HAND-BOOK

OF THE

TERRESTRIAL GLOBE;

OR,

GUIDE TO FITZ'S NEW METHOD OF MOUNTING AND OPERATING GLOBES.

(DESIGNED FOR THE USE OF FAMILIES, SCHOOLS, AND ACADEMIES.)

BY ELLEN E. FITZ.

BOSTON:
GINN AND HEATH.
1878.

HAND-BOOK

OF THE

TERRESTRIAL GLOBE;

OR,

GUIDE TO FITZ'S NEW METHOD OF MOUNTING AND OPERATING GLOBES.

DESIGNED FOR THE USE OF FAMILIES, SCHOOLS, AND ACADEMIES.

BY ELLEN E. FITZ.

BOSTON:
GINN AND HEATH.
1878.

Cambridge:
Press of John Wilson and Son.

PREFACE.

THE following pages are designed solely as an accompaniment to Fitz's Globe. They therefore contain only the text which is thought to bear expressly upon the use of this globe. A brief Appendix, comprising an historical account of globes, with a few details respecting their construction, forms the single exception. I am happy to render acknowledgments to Prof. G. A. HILL of Harvard College, from whom I have received valuable aid in the preparation of the book.

As regards the practical teaching of the subject, it is suggested that it would be well to have the learner first study thoroughly the first 71 articles of Part I.; then take the Description of the Globe (in connection, of course, with the Globe itself); and then proceed to the Problems, going back to the remaining articles of Part I. when he comes to the Problems which refer to the subjects explained in those articles.

It is intended in a future edition to enlarge this manual, giving it more the form of an Astronomy, and having a portion of it adapted to the use of a celestial globe.

E. E. F.

WATERTOWN, January, 1876.

CONTENTS.

PART I.

PART II.

PROBLEMS.

ILLUSTRATIONS.

NEW METHOD

OF

MOUNTING AND OPERATING GLOBES.

PART I.

SECTION I.

GEOMETRICAL DEFINITIONS.

1. A **point** has position, without length, breadth, or thickness.

2. A **line** has length, without breadth or thickness.

3. A **straight line** has the same direction between any two of its points.

4. A **curved line** or **curve** changes its direction at every point.

5. A **surface** has length and breadth, without thickness.

6. A **plane** is a surface, such that, if any two of its points be joined by a straight line, this line will be wholly in the surface. No surface that can be made is a perfect plane surface, in the strict mathematical sense of the term. But the surface of a table, if carefully made, is very nearly a plane; and the test employed by the maker consists in laying a straight rule, called by him a *straight edge*, on the surface, when its entire length ought to be in contact with the surface. A plane corresponds to what is commonly known as a *flat* surface.

Every surface which is not a plane, or composed of plane surfaces, is a **curved surface**.

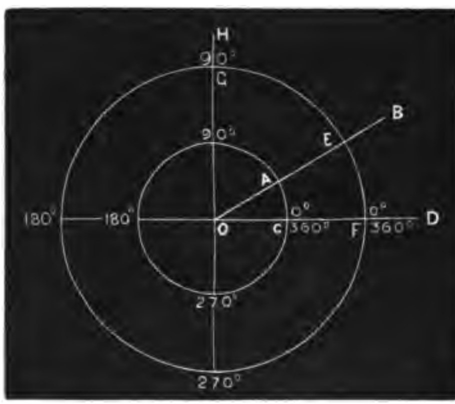
7. A **circle** is a plane bounded by a curve, called its *circumference*, which is everywhere equally distant from a point within, called the *centre*.

8. The **radius** of a circle is a straight line drawn from the centre to any part of the circumference.

9. The **diameter** of a circle is any straight line passing through the centre, and terminated on both sides by the circumference. A diameter is evidently equal to two radii.

10. An **arc** of a circle is any portion of the circumference. An arc equal to one-fourth of the circumference is often called a **quadrant**. The straight line joining the extremities of an arc is called the **chord** of the arc.

Fig. 1.



11. An **angle** is the difference of direction between two lines meeting (or tending to meet) in a point, called the **vertex** of the angle. Thus, in the figure, the lines A B and C D form an angle; these lines, if prolonged, meet at the vertex O, forming the angle B O D.

Angles are usually measured by means of circular arcs, the vertex of the angle being the centre of the circle. It is shown, in geometry, that angles having their vertices at

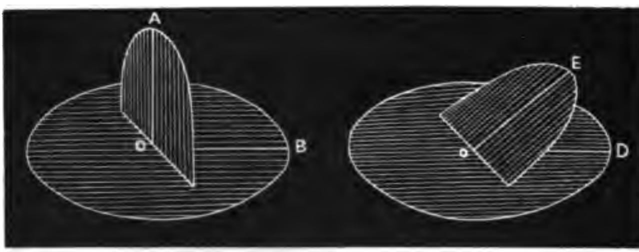
the centre of the same, or of equal circles, are to each other as the arcs intercepted between their sides. Thus, in the figure, the angles B O D and B O H are to each other as the arcs E F and E G. In order to express conveniently the values of arcs as the measures of angles, the circumference of a circle is divided into 360 equal parts, called degrees (marked °), each degree into 60 equal parts, called minutes ($'$), and each minute into 60 equal parts, called seconds ($''$). Then the number of degrees, minutes, and seconds, in the arc intercepted by the sides of an angle, is **taken as the measure** or value of the angle itself. Thus the value of the angle B O D is expressed by the number of degrees, &c., contained in the arc E F.

It is evident that the absolute length of a degree will differ in different circles, being proportional to the radius of the circle. In other words, the greater the radius of the circle, the greater the length of a degree: whence it follows that the arc included between the sides of an angle, whether these sides be longer or shorter, will always contain the same number of degrees. Thus, in the figure, the arcs A C and E F contain each 30 degrees, or one-third of their respective quadrants. Hence we may take, as the measure of an angle, *any* circular arc whatever intercepted between the sides of the angle, and having its centre at the vertex of the angle. An angle of 90°, or one measured by a quadrant, is called a **right angle**. In the figure, D O H is a right angle. When arcs are employed to express the values of angles in degrees, &c., they are often called **angular distances**.

When two planes intersect each other, they are said to form an angle with each other, called a **diedral angle**: the planes are called the *faces* of the angle; and their line of common intersection, the *edge* of the angle. A diedral angle is measured by the angle contained between two lines,— one drawn in each face, and both perpendicular to the common intersection at the same point. It is obvious that the

angle formed by any pair of lines thus drawn is equal to the angle formed by any other pair. An open book may serve to illustrate what is meant by a diedral angle. The two sides of the open book are the planes, the back of the book represents their intersection, and the angle of any pair of lines of the print tending to meet at the same point of intersection on the inside of the back edge is the measure of the diedral angle formed by the planes of the sides.

Fig. 2. Fig. 3.



A right diedral angle. An oblique diedral angle.

12. A **solid** has length, breadth, and thickness.

13. A **sphere** is a solid terminated by a curved surface, all the points of which are equally distant from a point within, called the **centre**. A sphere may be formed or generated by the revolution of a semicircle about its diameter.

14. The **radius** of a sphere is a straight line drawn from the centre to any part of the surface.

15. The **diameter** of a sphere is a straight line passing through the centre, and terminated on both sides by the surface. It is equal to two radii.

16. Every section of a sphere made by a plane is a circle. (For proof, consult some work on geometry, as Chauvenet's Geometry, p. 245.)

An apple, roughly speaking, may be considered as a sphere. Cut it into two parts, and each cut surface is a circle.

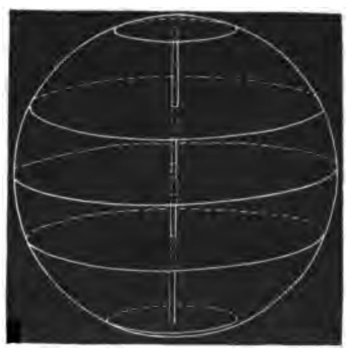
17. A circle which divides a sphere into two equal parts, called **hemispheres**, is called a **great circle**. Two great circles of the same sphere bisect each other, since their line of intersection is a diameter of the sphere.

18. A circle which divides a sphere into two unequal parts is called a **small circle**.

Cut an apple into two equal parts, and each cut surface is a great circle; cut it into two unequal parts, and each cut surface is a small circle.

19. The **poles** of a great circle of a sphere are the extremities of that diameter which is perpendicular to the circle; and these extremities are also the poles of all small circles parallel to the great circle. Cut an apple into slices across its core, and the stem and blossom, or extremities of the core, are the poles of all the slices.

Fig. 4.



Great and small circles.

20. Angular Motion. — When a body is continually changing its direction with respect to another body which is considered to be at rest, it is said to have an *angular motion* around this other body. The simplest case of this kind of motion is that of a point proceeding around the centre of a circle upon the circumference. The end of the minute-hand of a watch, for example, has an angular motion around its pivot, such that it describes a complete circle, or 360°, every hour.

Angular velocity is the rate or degree of rapidity of angular motion, and is measured by the angle described in one unit of time, — second, minute, hour, or day, as the case may be. The angular distance passed over in any time is equal to the angular velocity multiplied by the time.

SECTION II.

GEOGRAPHICAL DEFINITIONS.

21. THE earth, in shape, is very nearly a sphere, or globe. More exactly, it has the form of a globe slightly flattened around the ends of a certain diameter, called, for a reason mentioned hereafter, the *axis* of the earth. This figure is known among mathematicians as the oblate spheroid. The amount of the flattening, in the case of the earth, is very small, being only $\frac{1}{300}$th part of the length of the axis. A globe 25 feet in diameter would be brought to the same proportions by reducing this diameter, in one direction, the amount of one inch.

The *circumference* of a great circle of the earth is about 25,000 miles; the *diameter* of such a circle is about 8,000 miles. The smallest or axial diameter of the earth is 26 miles less than its greatest diameter.

For the purpose of determining the relative positions and distances of points on the earth's surface, certain imaginary circles are supposed to be drawn upon its surface.

22. A **terrestrial globe** is a hollow ball or sphere, upon whose surface is delineated a map of the earth, having drawn upon it the imaginary circles above referred to.

23. The **axis** of the earth is the diameter about which it rotates, like a wheel about an axle. (This motion is considered at length in Sect. IV.)

24. The **poles** are the extremities of the axis. The one nearer to North America is called the **north pole**: the other is called the **south pole.**

25. The **equator** is a great circle passing around the earth midway between the poles. It divides the surface of the earth into a *Northern* and a *Southern Hemisphere.*

26. Meridians are great circles passing through the poles, and crossing the equator at right angles. Every place on the earth's surface may be supposed to have a meridian passing through it.

Note.—The word "meridian," as generally used, means a half of the great circle which it designates, rather than the whole.

27. Parallels of latitude are small circles parallel to the equator. The farther a parallel is from the equator, the smaller is its diameter. Every place on the earth's surface (except places on the equator) may be supposed to have a parallel passing through it.

28. The **tropics** are two parallels at a distance of 23½° from the equator. The one north of the equator is called the Tropic of Cancer; the other, the Tropic of Capricorn.

29. The **polar circles** are two parallels at a distance of 23½° from the poles. The one surrounding the north pole is called the Arctic Circle; the other, the Antarctic Circle. (For the reason of the position of the tropics and polar circles, see p. 34, Art. 71.)

30. The tropics and polar circles divide the surface of the earth into five **zones**: namely, one torrid, lying between the tropics; two temperate,—a northern and a southern,—extending beyond the tropics to the polar circles; and two frigid,—a northern and a southern,—extending beyond the polar circles to the poles.

31. Latitude is the angular distance of a place from the equator, measured on its meridian. Distance from the equator towards the north pole is called north latitude; from the equator towards the south pole, south latitude. Places situated on the equator have no latitude; in other words, the latitude of such places is zero. Latitude near the equator is called *low* latitude; near either pole, *high* latitude. The highest latitude is 90°, or the distance of either pole from the equator. Every point on the same parallel has the same latitude.

32. Longitude is the angular distance between two meridians, measured upon the equator or a parallel, — one of the meridians passing through the place whose longitude is required; and the other being employed, by common consent, to reckon from. In England, and usually in the United States, longitude is reckoned from the meridian passing through Greenwich, near London. Distance to the right of the meridian of Greenwich is called east longitude; to the left, west longitude. Places situated upon the meridian of Greenwich have no longitude. The meridian from which longitude is reckoned is often called the First Meridian. Every point on the same meridian (*a*) has the same longitude.

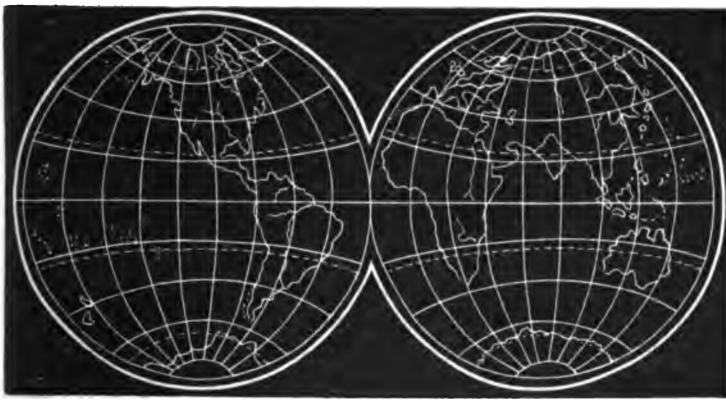
33. Any two meridians include between them, whether measured upon the equator or a parallel, an arc having the same number of degrees; for the planes of these meridians form a diedral angle, which is measured by the angle of any pair of lines drawn, one in each meridian plane, from a common point of the intersection of the plane (which is the earth's axis), perpendicular to the intersection. If the pair of lines be drawn from the middle of the axis, their angle is measured by the arc of the equator included between them; if from any other point of the axis, by the arc of the corresponding parallel included between them. Therefore these arcs must contain the same number of degrees. (See angle, including diedral angle, Art. 11.) But the absolute length of the intercepted arcs, and of each degree on the arcs, is in proportion to the length of the radii of their several circles, according to the explanation already given in treating of an angle.

34. The definitions of meridians, parallels of latitude, &c., are illustrated in fig. 5. Meridians are drawn at intervals of 20°. Parallels of latitude, including also the

(*a*) "Meridian" here really means a semi-meridian passing between the poles.

equator, are drawn at intervals of 18° between the poles. The tropics and polar circles are represented by dotted lines.

Fig. 5.



SECTION III.

ASTRONOMICAL DEFINITIONS.

35. THE imaginary concave surface in which a spectator at first conceives all the heavenly bodies placed is a hemisphere, in the centre of the base of which he himself is situated. The entire sphere is commonly called, in astronomy, the **celestial sphere**. For the purpose of defining the positions of the heavenly bodies within this sphere, it is found convenient to make use of certain imaginary lines, and positions of reference, similar to those which are employed for a like purpose on the earth's surface.

36. If the axis of the earth were extended indefinitely in the direction of the north pole, it would pierce the celestial sphere in a point called the **north celestial pole**;

if the axis of the earth were extended indefinitely in the direction of the south pole, it would pierce the celestial sphere in a point called the **south celestial pole.** These points coincide with two fixed points within the celestial sphere, around which the stars that do not rise and set appear to move in circles.

37. If the plane of the terrestrial equator were extended indefinitely, it would intersect the celestial sphere in a great circle, called the **celestial equator.**

38. If the plane of the terrestrial meridian of a place were extended indefinitely, it would intersect the celestial sphere in a great circle, called the **celestial meridian** of the place.

39. **Circles or Parallels of declination** are small circles of the celestial sphere parallel to the equator.

40. **Hour circles** are great circles of the celestial sphere passing through the poles, and intersecting the equator at right angles.

41. The base of the celestial hemisphere which is visible at any place is called the **plane of the horizon.** The great circle in which this plane intersects the celestial sphere is called the **horizon.** Astronomers sometimes distinguish between two horizons, called respectively the **sensible** and the **rational** horizon. This distinction is rather between the planes of these horizons than the horizons themselves. The plane of the sensible horizon at any place is an imaginary plane passing through the place, perpendicular to the earth's radius at that place. The plane of the rational horizon of the place is a plane parallel to that of the sensible horizon, and passing through the earth's centre. These two planes apparently meet in the same great circle, at the distance of the celestial sphere.

42. The **zenith** is the point within the celestial sphere which is over the head of a spectator upon the earth's surface. The **nadir** is the point which is under his feet, or diametrically opposite his zenith.

43. Vertical circles are great circles passing through the zenith and nadir, and intersecting the horizon at right angles.

That vertical circle which intersects the celestial meridian at right angles is called the **prime vertical**.

44. The four points where the meridian and prime vertical intersect the horizon of any place are called the **cardinal points** of the horizon; those of the meridian, the *north* and *south* points; those of the prime vertical, the *east* and *west* points. These latter points are evidently the poles of the meridian; and, since the celestial equator is a great circle perpendicular to the meridian, it must pass through them.

45. The **altitude** of a celestial body is its angular height above the horizon, measured on a vertical circle. When this distance is measured on the celestial meridian of any given place, it is called **meridian altitude**.

46. The **zenith distance** of a celestial body is its angular distance from the zenith. It is the complement of the altitude.

47. The **azimuth** of a celestial body is its angular distance, measured on the horizon, between the north or south points (according to the hemisphere in which the observation is made) and the point in which a vertical circle passing through the body intersects the horizon.

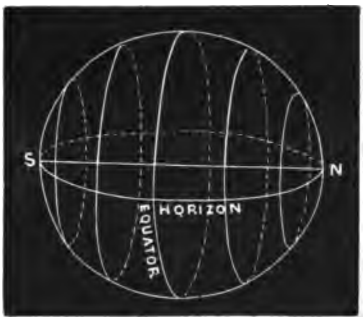
48. The **amplitude** of a celestial body is its angular distance from the east point when it rises, or from the west point when it sets.

49. The **declination** of a celestial body is its angular distance from the equator, either north or south. Declination corresponds to terrestrial latitude.

50. The **right ascension** of a celestial body is the arc of the celestial equator included between two hour-circles, — one passing through the body; and the other through a point on the celestial equator, called the *vernal equinox*. Right ascension corresponds to longitude on the earth; but, unlike longitude, it is always reckoned towards the east.

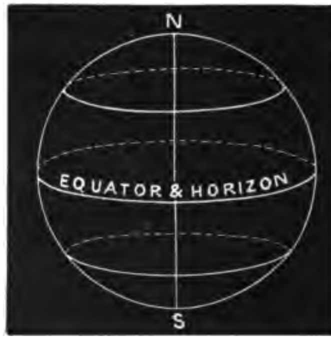
51. At the equator the celestial poles are in the horizon; and hence the celestial equator, and parallels of declination, are all perpendicular to the horizon. This position of the sphere is called **a right sphere.**

Fig. 6.



Right sphere.

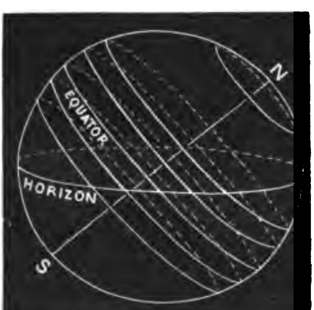
Fig. 7.



Parallel sphere.

52. At the terrestrial poles, the celestial poles appear in the zenith, and the celestial equator coincides with the horizon. The parallels of declination are parallel to the horizon. This position of the sphere is called a **parallel sphere.**

Fig. 8.



Oblique sphere.

53. At all places, except the equator and poles, the celestial equator, and parallels of declination, are oblique to the horizon. This position of the sphere is called an **oblique sphere.**

54. The apparent path of the sun traced on the surface of the celestial sphere, among the fixed stars, is a great

circle, which he moves over in a direction from west to east. This circle is called the **ecliptic**, because eclipses take place when the moon, at the new and full, is in or near this circle. The ecliptic is inclined to the celestial equator at an angle of about 23½°.

In order that we may define at any time the position of the sun in the ecliptic, this circle is supposed to be divided into 12 equal parts, called signs, each containing 30°. These signs are distinguished into Spring, Summer, Autumn, and Winter signs. These, with their symbols, are as follows: —

Spring Signs.	*Summer Signs.*	*Autumn Signs.*	*Winter Signs.*
♈ Aries.	♋ Cancer.	♎ Libra.	♑ Capricornus.
♉ Taurus.	♌ Leo.	♏ Scorpio.	♒ Aquarius.
♊ Gemini.	♍ Virgo.	♐ Sagittarius.	♓ Pisces.

The sun enters these signs upon dates varying from the 19th to the 23d of the several months. For the sake of convenience, the signs are often considered as beginning on the 21st of each month.

The **cardinal signs** of the ecliptic are Aries, Cancer, Libra, and Capricornus. There are four **cardinal points** on the ecliptic, called the *equinoctial* and *solstitial* points, which at present have the following positions for the northern hemisphere: *Vernal equinox*, the first degree, or, as it is usually called, the first point, of Aries; *autumnal equinox*, the first point of Libra; *summer solstice*, the first point of Cancer; *winter solstice*, the first point of Capricornus. These points mark important positions of the sun within the ecliptic, as referred to the equator: thus the solstitial points are the points in which the sun attains its farthest positions north or south of the equator; and the equinoctial points are the points in which the sun crosses the equator, or where the equator and the ecliptic intersect each other.

55. Since the circles of the celestial sphere coincide in

position with those defined upon the earth's surface (excepting the ecliptic), they may be represented by the latter as drawn upon a terrestrial globe. The ecliptic, to which no terrestrial circle corresponds, may therefore have its relative position within the heavens represented either upon a celestial or a terrestrial globe.

SECTION IV.

PHENOMENA CAUSED BY THE MOTIONS OF THE EARTH.

56. EVERY morning, the sun makes his appearance upon the eastern horizon, ascends above it until noonday, then descends, disappearing at last beneath the western horizon. At night, the moon is often seen pursuing a similar track across the heavens; and the watcher of the stars sees them one by one rise, describe a course along the sky, and set, until the sun again returns to eclipse them with his superior light, and to repeat his daily journey towards the west. Again: if, at the same hour for several successive nights, the position of a star, or group of stars, be noted, it will appear (*a*) to be moving westward at the rate of about 1° during the twenty-four hours, this constant change of position amounting to an entire circuit during a year.

57. We thus recognize two distinct movements of the heavenly bodies; namely, a daily motion of revolution, and a motion of revolution which is completed in just a year. The question now arises, Are these two movements real, or only apparent? that is, do they belong to the heavenly bodies themselves, or has the earth a system of move-

(*a*) The fact being that the stars are at rest while the sun really moves eastward.

ments to which they may be referred, as objects upon a roadside change their positions with reference to a passing carriage?

58. It may appear, at first thought, strange to associate ideas of motion with an earth which has always seemed so stable to its inhabitants; but experience teaches us that it is not at all times an easy matter to distinguish between the two states of *motion* and of *rest*. When, for example, we travel by night, deprived of the view of all objects outside of the vehicle in which we are seated, we are conscious of no *sense of progress*, notwithstanding that we feel the tremor with which the vehicle is carried over the inequalities of the road. The traveller who looks from a car-window, as he journeys swiftly along, receives a very strong impression that the objects of the landscape are making as swift a transit in an opposite direction. The aeronaut testifies, that, as he rises or descends in his car, it is the earth which seems to move from him, or to return to him. A ship swings round in a land-locked bay, and one looking out of the cabin-window fancies the whole shore to pass in the direction of a circle around him. And so we might continue to enumerate instances tending to prove that the senses alone, unassisted by experience or judgment, are often incapable of ascribing a change of place to its proper source.

59. It is evident, then, that, so far as our vision is concerned (and this is the only sense by which we are made aware of the movements of the heavenly bodies), these movements may belong either to the heavenly bodies themselves, or, with just as good a show of reason, to the earth. Now, which is the more probable supposition, considering at first only the *daily* motion? Do thousands, or rather millions, of celestial bodies at vast distances, and many of them of immense magnitudes, perform a diurnal revolution about the earth in twenty-four hours? or does the earth rotate about an axis in this time? The latter

hypothesis would ascribe the effect to the simplest cause, and is unquestionably the more reasonable one.

60. But there are experiments and reasons, which, to the minds of those who understand them, are as convincing proofs of the earth's rotation as though they, from some distant stand-point, actually saw this rotation going on. In the first place, it has been found that the weight of a body increases when carried from the equator towards the poles. Now, the generation of a centrifugal force by means of rotation — this force being the greatest where the earth's surface has the swiftest motion, or at the equator — would account for such a variation in weight; for such a force, being directed away from the earth's centre, diminishes, according to its amount, the weight of a body, which is a force directed towards the centre of the earth.

Experiments of another character have demonstrated that the *very shape* of the earth is a strong proof of its rotation. This shape, as we know, is that of a sphere flattened at the poles, and bulging at the equator. Now, it is found that when a rotation equal to that of the earth in amount, or performed once in twenty-four hours, is given to a fluid or semi-fluid mass, this soon assumes the same spheroidal shape which the earth is known to have. Thus a mass of oil, placed within a transparent liquid of the same density, retains the form of a perfect sphere while at rest, but changes this form for that of a spheroid the moment a slow motion of rotation is given to it by means of a piece of wire forced through it. The theory that the earth was once intensely heated, and therefore fluid, is rendered highly probable by geological and cosmical considerations, and by the still heated condition of the interior of the earth.

There are, also, experimental proofs of the earth's rotation, of the most direct and conclusive character, such as Foucault's famous pendulum experiment; but, for an explanation of these, the learner must consult other and larger works.

61. The daily or nightly movement of the heavenly bodies is much more evident to the eye than the much slower annual motions of certain of them, like the sun and moon. The latter, however, may be readily observed by comparing the positions of these bodies with respect to the fixed stars for a few consecutive nights. So far as the sun is concerned (which is the only body whose annual movement we consider), its annual motion consists in the description of a great circle among the fixed stars already defined as the ecliptic. The apparent annual motion of the sun within this circle may be explained by supposing either that the sun moves round the earth, or the earth round the sun, just as we had a similar choice of explanation when considering the apparent daily motion of the same body. That the latter is the case is rendered probable in the highest degree from certain phenomena, as the aberration of light, and certain well-known physical laws, an explanation of which belongs rather to a work upon astronomy than to the present brief treatise.

62. The annual motion of the earth round the sun is performed in such a manner, that at all times the earth and the sun lie very nearly, or, as we shall suppose, exactly, in one and the same plane, called the *plane of the ecliptic.* The intersection of this plane with the surface of the heavens is the ecliptic, already otherwise defined in Art. **54.** In this plane the orbit of the earth is a certain curve, called in geometry an *ellipse;* a figure differing from a circle by being more or less oval in form, and also in having *two* points within, to which its circumference is referred, instead of one central point, as in the circle. These two points are called the *foci* of the ellipse, and in one of these foci the sun is situated. In the figure, A and B represent these points.

Fig. 9.

The distance of A or B from the nearest point in the ellipse of Fig. 9 is much less than their distance apart; but in the case of the orbit of the earth it is quite the contrary, the foci there being very much nearer to each other than they are distant from their ellipse. This is because the orbit of the earth approaches much more nearly the form of a circle than the ellipse of Fig. 9.

Now, since the sun does not occupy the centre of the earth's orbit, but one of the foci, it follows that the earth is nearer to it at one time than another. When these two bodies are nearest together, we say the earth is in *perihelion;* when they are farthest apart, we say it is in *aphelion.* These two positions are represented in Fig. 12, page 31. The earth advances around the sun at its slowest rate when it is in aphelion, and at its fastest rate when it is in perihelion. It is in perihelion upon January 1, and in aphelion upon July 8. The distance of the earth from the sun, when in perihelion, is about 90,000,000 miles; when in aphelion, 93,000,000; the former distance being $\frac{29}{30}$ths of the latter.

The orbit of the earth is more than half a billion miles in extent. The earth moves in this orbit at the rate of 68,000 miles an hour, or with a velocity of about 19 miles a second.

Fig. 10.

63. The earth moves in its orbit from west to east. A motion of revolution from west to east may be defined as motion in a *direction contrary to that in which the hands of a clock move,* the spectator being supposed to be situated at the north pole, with his face towards the sun. The direction in which the sun appears to move along the ecliptic is the same as that of the real motion of the earth in its orbit, or towards the east. Fig. 10 illustrates the relative direction

of the earth and sun in their respective yearly courses, real and apparent. When the earth is at A, the sun will be seen in the direction of the line A D, or as if projected on the surface of the sky among the stars at D. When the earth has reached the position B, the sun will be seen projected upon E; while, with the earth in the position C, the sun will be seen projected upon F. The sun has therefore seemed to move from D to F, while the earth has advanced from A to C; and thus the apparent movement would continue around the entire circle in a direction towards the east, or the same as that of the earth in its orbit. This sameness of direction is, on the contrary, not met with in the real and the apparent *diurnal* motions, the directions of these being opposed to each other: the sun moves from east to west across the sky, while the earth rotates upon its axis from west to east.

64. The axis of the earth is not perpendicular to the plane of its orbit, or plane of the ecliptic, but is inclined towards it 23½°; that is, the axis makes an angle of 23½° with a line drawn perpendicular to the plane of the earth's orbit, and therefore an angle of 90–23½° or 66½° with the plane of the orbit itself.

It follows, from this inclination of the earth's axis to the plane of its orbit, or plane of the ecliptic, that this plane has also an inclination of 23½° to the plane of the equator, as stated on page 19. This may be illustrated by supposing the earth to move around the sun half immersed within the surface of an ocean, and having its axis in an upright position, when the equator would everywhere rest upon the ocean, or the planes of the ecliptic and of the equator would coincide. Now, incline the axis one or more degrees, and straightway the equator, which is a part of the same sphere, falls below the ocean the same number of degrees along half of its extent, and rises above it the same number of degrees along the other half; or the planes of the ecliptic and of the equator now form an

angle with each other, just equal to that formed by the earth's axis with a perpendicular to the plane of the ecliptic.

65. During the annual journey of the earth around the sun, its axis constantly preserves the same direction in space; or, to express the same fact in other words, *the earth's axis always remains parallel to itself.* An illustration of this kind of motion is presented in the figure, where a pencil is held in one direction while it describes a circle. The four positions of the pencil are all parallel to each other, and to any number of positions which may be represented, so long as the direction of the pencil remains the same. In the same way, the axis of the earth, along with the earth, moves round the sun, preserving a constant direction all the time.

Fig. 11.

It may be said that the pencil, in its several positions, is directed, above and below, towards different points in the space beyond; whereas we know, by observation, that the earth's axis always appears to be directed towards the same points in the heavens. The reason of this lies in the fact that the distances from the earth of the only visible fixed points in the sky (namely, the fixed stars) are so enormous, that, by comparison, even the diameter of the earth's orbit (about 180,000,000 miles) shrinks into all but a mere point. The diameter of the earth's orbit, when stated in miles, is a length so great, that the mind fails to form an adequate conception of it. What, then, can be said of the distance of even the nearest fixed star, except that it is known to be more than 200,000 times as great,

and that light, travelling 190,000 miles a second, requires 3½ years to pass from the star to the earth? Viewed from a fixed star, therefore, not only the earth, but the earth's orbit, becomes a mere point in space; and, on the other hand, it follows, that, as seen from any part of the earth's orbit, a fixed star must always appear to have the same position in the sky.

66. The alternation of day and night is caused by the rotation of the earth on its axis once every 24 hours. The earth, therefore, at every instant is divided into two shifting hemispheres, one illuminated by the sun, and the other not illuminated. If the sun were a small shining body placed very near the earth, it would illuminate only a small portion of its surface. This may be readily seen by holding a lighted match or taper near a sphere or globe in a dark room. Now, the larger the luminous body, the greater the extent of surface illuminated by it; also, the more distant the luminous body (the light being supposed to be sufficiently intense), the greater the amount of surface thus illuminated. In the case of the sun, its size and distance, and the intensity of its light, are so great, that it illuminates almost precisely one-half of the earth's surface at all times. In other words, at every instant the sun is above the horizon at all places on one-half of the earth's surface, and below it at all places on the other half. The line around the earth separating the surfaces of the illuminated and unilluminated hemispheres must be a great circle. This great circle is often called the *circle of illumination*, or, when represented on a terrestrial globe, the *day-circle*, — a name by which we shall call it hereafter.

In order to illustrate the alternation of day and night, we may again imagine the earth floating on an ocean, with exactly one hemisphere below the surface of the water. Then the hemisphere which is above the surface may fitly represent the hemisphere which is illuminated by the sun's

rays, while the immersed hemisphere answers to that half of the earth's surface over which night prevails. To make the conditions as simple as possible, suppose further, that the poles of the earth, with the entire axis of course, lie exactly on the surface of the water. Then it is plain that exactly one-half of every parallel (equator included) must be above the surface of the water, — that is, in light; and that the other half must be below this surface, — that is, in darkness: for the centre of every parallel is situated in the axis, and therefore in the surface of the water. Now, let the earth be supposed to rotate uniformly on its axis in 24 hours, and it is evident that every place on every parallel must be just 12 hours above the surface of the water, or in light, and 12 hours below, or in darkness; or, in other words, under these conditions there would be a day and a night of 12 hours each over the entire earth.

67. Such a rotation of the earth as we have described must produce, every 24 hours, two equal periods, — one of light, or day; the other of darkness, or night. Now, as a matter of fact, except at the equator, this is true only twice a year; viz., on March 21 and September 21. At all other times, as we well know, these periods are not only different in length, but, moreover, they undergo variations in length, in the course of the year. And still further: the length of the day (or the night) is different on different parallels at the same time of the year. Let us consider the chief facts respecting these differences in something like regular order. In the first place, in this part of the world, we have the longest day in June, and the shortest in December; while, as to the nights, it is just the other way, — the shortest occurring in June, and the longest in December. We might know that the longest day must correspond to the shortest night from the fact that the sum of the two must be always the same; viz., 24 hours, or the time of one revolution of the earth on its axis. Moreover, as we all know, the length of the day gradually diminishes from about the

21st of June to the 21st of December, when it reaches its shortest limit: it then begins to increase, at first slowly, afterwards more rapidly through the months of late winter and of spring, until, when the 21st of June again comes round, it again reaches its greatest length. During the succeeding year, it goes through the same changes in the same order. On the other hand, the changes in the length of night, of course, are exactly the reverse of those of day.

If we lived in some other part of the world, — say, at a place nearer the north pole, as the southern part of Greenland, — we should find that similar changes in the lengths of day and night occurred during the year, but with this important difference, — that they were much greater in amount. For instance: June 21 is the longest day in the year; but instead of being about 15 hours' duration, as at Boston, it lasts at least 20 hours, followed by a short night of 4 hours, or rather a period of 4 hours of twilight; since the sun remains so near the northern horizon, that the light of day is but partly removed even at midnight. On the other hand, if we take a position near the equator, we find, that, while the same changes occur, they are less in amount than with us. Finally, on the equator itself, there is no change in the duration of day and night, each being 12 hours long throughout the year. In the southern hemisphere, it is found that changes take place in the exact inverse order to those which occur in the northern hemisphere. For example, when the day is 16 hours long at a place north of the equator, there is a night of 16 hours at any place which is just as far south of the equator. It appears, in short, that these changes in the duration of day and night are in some way dependent upon the *latitude* of the place, being always greater in high latitudes than in low ones.

68. Still further: it is a matter of common observation, that the sun rises and sets at very different points of the horizon during the year; and also, that, at the hour

of noon, it is much nearer the zenith at certain seasons of the year than at others. In summer, when the days are long, it rises far to the north of the east point of the horizon; mounts up into the heavens, until at noon it is nearly overhead; then sets at a point as much to the north of west as the rising point was north of east. In mid-winter, on the other hand, when the days are short, the sun's brief course through the sky lies low down towards the southern horizon. It rises in the south-east, and sets in the south-west; and, even at noon, is not far above the southern point of the horizon. Thus it would seem that the noonday height of the sun is in some way intimately related to the length of the day; and we are very naturally led to suspect that the changes in both are due to the action of a common cause. This cause is to be found by a study of the annual motion of the earth round the sun in the plane of the ecliptic, with its axis preserving a constant direction in space at all times, as explained in Art. **65**. We might easily study this motion by the aid of the mental image of the earth moving in an ocean, which we have already employed in Arts. **64** and **66**.

69. But we shall obtain a more comprehensive view of the subject by examining directly the various positions which the earth has relatively to the sun during the year, as they are represented in Fig. 12. In this figure, twelve positions of the earth in its orbit are shown; and in all these positions the earth's axis is represented as constant in direction, and making an angle of $66\frac{1}{2}°$ with the plane of the ecliptic.

Twice in the year, — viz., at the positions marked vernal and autumnal equinox, — the sun shines from pole to pole, and is vertical at the equator. This is upon March 21 and September 21. In these two positions, in fact, the earth has exactly the same situation with regard to the sun that has been more fully explained in Art. **66**. Upon these two dates, therefore, day and night

are everywhere 12 hours in length, or the parallels of the earth's surface are divided into two equal parts by the day-

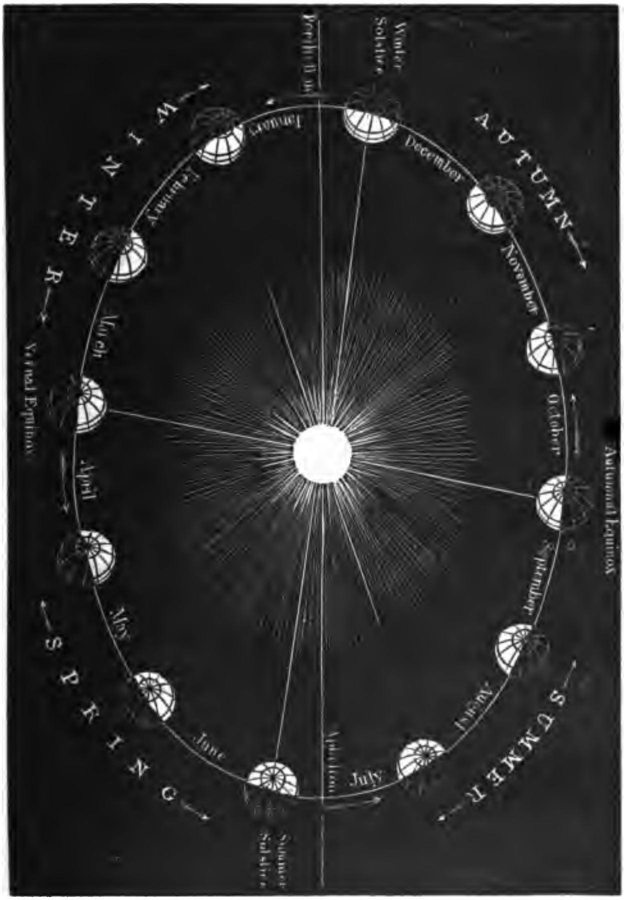


Fig. 12.

circle. The equator must be thus divided by the day-circle at all times, since both are great circles, and therefore must always bisect each other.

March 21 and September 21, from the equality of day and night at these times over all the earth's surface (unless we except the poles), are called the equinoxes (*a*), — the former the vernal, and the latter the autumnal. The names of these two dates are reversed in the southern hemisphere; March 21 being the autumnal, and September 21 the vernal.

Upon June 21 (see Fig. 12), the sun shines over the entire north frigid zone (which is included within the smallest parallel represented), and leaves the entire south frigid zone in darkness. Upon December 21, the sun shines over the entire south frigid zone, and leaves the entire north frigid zone in darkness. These two dates are called the solstices (*b*), since at these times the sun is stationary as regards his approach to the poles. June 21 is the summer solstice of the northern hemisphere, and the winter solstice of the southern hemisphere. December 21 is the winter solstice of the northern hemisphere, and the summer solstice of the southern hemisphere.

These are, then, four cardinal positions of the earth, as regards the sun; namely, the positions of the equinoxes and the solstices, these positions being attained about the dates of March 21, September 21, June 21, and December 21. The four seasons of the year, astronomically considered, begin with these dates.

70. Let us now, with the aid of Fig. 12, see how the change of day and night goes on between these several dates.

(*a*) From the two Latin words *æquus* and *nox*, meaning *equal* and *night*.

(*b*) From the two Latin words *sol* and *stare*, meaning the *sun* and *to stand*.

The equinoxes and solstices, properly speaking, are times or dates as above defined; although these terms are often applied to the points of the ecliptic corresponding to the dates, and, indeed, have been so defined on page 19.

From June 21 to September 21, in consequence of the motion of the earth in its orbit, the north frigid zone gradually has one-half of its area removed from the sun's light, while exactly the converse holds true of the south frigid zone. Day is therefore decreasing over the northern hemisphere, and increasing over the southern. From September 21 to December 21, the remainder of the north frigid zone is gradually removed from the sun's light. During this period, day continues to decrease over the northern hemisphere, and to increase over the southern. From December 21 to March 21, one-half of the north frigid zone is gradually brought again into the sun's light. During this period, day is increasing over the northern hemisphere, and decreasing over the southern. From March 21 to June 21, the remaining half of the north frigid zone is brought, by the earth's motion, into the sun's light. Day, therefore, continues to increase over the northern hemisphere, and to decrease over the southern.

We are thus enabled to see that the northern and southern hemispheres of the earth's surface alternate with each other as regards their situation with respect to the sun's rays; which alternation is a necessary result of the constant parallelism of the earth's axis during its revolution around the sun. Turn again to Fig. 11 for an illustration of this. The upper end of the pencil points away from the centre of the circle in one position, and towards it in the opposite position: the reverse, of course, is true with regard to the lower end. Between these two positions, the pencil is perpendicular to the radius of the circle. As regards this centre, therefore, the pencil moves its upper and its lower half reciprocally to and from it, there being a position midway in this movement, in which the halves are equally near to the centre of the circle.

It is also evident, from Fig. 12, that, *at any one time*, the nearer the parallel is to the pole, or the greater the latitude,

the greater will be the difference in the lengths of day and night.

71. We now learn why the tropics and polar circles are distinguished from the other parallels upon the earth's surface: for the former are the farthest parallels from the equator, which are illuminated by a vertical sun during the year; and the latter are the farthest parallels from the poles, which pass wholly out of, or wholly into, the sun's light.

72. When a parallel lies partly in the illuminated hemisphere and partly in the unilluminated, or is divided by the day-circle, it has a day and a night every 24 hours, or during every revolution of the earth upon its axis. When it lies wholly in one of these hemispheres, its day or its night continues until it is again divided by the day-circle. Now, as we have seen, parallels of the frigid zones are the only parallels, which, at certain times in the course of a year, are divided, and at other times are not divided, by the day-circle. These parallels are, therefore, subject to a greater variety of day and night, as regards length, than occurs within the temperate and torrid zones. They have, indeed, four distinctly marked periods during the year; these periods varying in length according to the distance of the given parallel from the pole.

Naming these periods in the most convenient way, they are, 1st, a period of continuous day, during which the parallel is wholly in the illuminated hemisphere; 2dly, a period of alternate day and night, during which the parallel is partly in the illuminated and partly in the unilluminated hemisphere; 3dly, a period of continuous night, during which the parallel is wholly in the unilluminated hemisphere; and 4thly, a second period of alternate day and night, during which the parallel is again partly in the illuminated and partly in the unilluminated hemisphere.

The middle of a period of continuous day, for either the northern or the southern hemisphere, is at the summer solstice for the corresponding hemisphere. The middle of

the succeeding period of alternate day and night is at the autumnal equinox. The middle of a period of continuous night is at the winter solstice. The middle of the succeeding period of alternate day and night is at the vernal equinox.

73. As an instance of this variety of day and night within the frigid zones, let us see how it is exhibited at Spitzbergen during the year. Day gradually increases in length, from a momentary glimpse of the sun on February 21 to 12 hours on March 21; then to 24 on April 21, when it remains continuous until August 21: it then alternates with night, decreasing from 24 hours to 12 on September 21, and to a parting glimpse of the sun on October 21; when a continuous night of four months succeeds.

Farther south, as in the southern part of Nova Zembla, we should find a continuous day and night of about 6 weeks each, and periods of alternate day and night of 20 weeks each. Farther north, on the contrary, we should find that the periods of alternate day and night are shorter, until, at the pole, they cease altogether, and the two periods of continuous day and of continuous night, each six months in length, compose the year.

The greatest length of day within the torrid zone is about 13½ hours, this length occurring upon either tropic. The greatest length of day within the temperate zones obtains upon the polar circles, where it is 24 hours. The length of any given day subtracted from 24 hours gives the length of the night, and *vice versa.*

74. Owing to the variable rate at which the sun moves between the tropics, the relative length of day and night, *at the same place,* also changes at a variable rate. Thus this change proceeds the slowest at the times of the solstices, and the fastest at the times of the equinoxes. The reason of this is to be found in the varying inclination of the sun's motion along the ecliptic to the equator. Thus, for some time before and after the solstices, the sun is describing

an arc of the ecliptic (40° or 50° in length), which is nearly parallel to the equator on both sides of the solstitial points; consequently the change in the sun's declination during this period is very small. During this period, therefore, the sun describes diurnal circles which nearly coincide, and the length of day is nearly constant. On the other hand, about the time of the equinoxes, the sun's motion has the greatest inclination to the equator; and, therefore, the change in the length of day is most rapid. The following is an estimate of the rate at which its declination increases from the time of the vernal equinox. From March 21 to April 21, the sun moves northward about 10°; from April 21 to May 21, about 9°; and from May 21 to June 21, about 4°. The same cause also affects, to the same extent, the rate at which the sun moves to and from the zenith between successive noondays, and also determines the rate at which it advances along the horizon between successive sunrises or sunsets.

75. It follows, from the equality in the rate at which the sun is changing in declination at dates equally removed from either solstice, that the earth's surface is illuminated precisely in the same manner on any pair of such days. Hence for every day in the year, except those two which date at the solstices, or the longest and the shortest day, there corresponds another day of the year equal to it in length; and hence, also, at dates equally distant from either equinox, the sum of the lengths of the two days (or of the two nights) must just equal 24 hours.

76. Every place upon the earth's surface has 6 months of day during the year, and 6 months of night. At the poles, the year is divided into a day and a night of 6 months each; at the equator, every 24 hours is divided equally into a day and a night. At places between these two positions, the sum total of the length of day and night is known from this: For every day shorter than 12 hours during the year, there corresponds one just as much longer;

and the same is true of night; making the average length of each 12 hours for the year; in which time the total length of each must, of course, sum up to 6 months, as at the equator.

THE DIURNAL COURSE OF THE SUN.

77. The varied changes in the length of day and night may be also studied to advantage by examining the diurnal course of the sun with reference to the horizon of a place during the year.

The daily motion of the earth upon its axis from west to east causes an apparent motion of the sun across the sky from east to west. Now, it is evident that the apparent motion must be at the same rate as the real; that is, the sun moves both above and below the horizon at the rate of 15° every hour, or 1° every 4 minutes. This motion is performed in a great circle (viz., the celestial equator) when the sun is vertical at the equator, or upon March 21 and September 21: at all other times, the diurnal circles described by the sun are small circles. An observer at the north pole upon March 21 or September 21 would be able to follow the sun's course completely round the celestial equator, which, at the pole, coincides with the horizon (see Fig. 7). In fact, at the pole, the sun is rising upon the former date, and setting upon the latter. If he continued to observe this course for three months subsequently to March 21, he would find that the diurnal circles described by the sun gradually decreased in size, just as parallels decrease from the equator to the tropics. The sun's diurnal course is not, however, an exact circle; since, while describing this course, it is changing in declination: it follows, in fact, the direction of a spiral.

The sun ascends about 10° above a polar horizon during the first month of the long polar day, 9° during the second, and 4° during the third; attaining a final distance of 23½° above it, after which it descends at a corresponding rate.

This motion of the sun from and to the horizon is identical with its change in northern declination.

The points of the compass are virtually abolished at the poles; the whole horizon being in the direction of south at the north pole, and of north at the south pole.

78. At the equator the sun always describes one-half of its diurnal circle above the horizon, and the other half below it. (See Fig. 6, illustrating a right sphere, page 18.) Upon March 21 and September 21 the sun rises in the east and sets in the west, not only at the equator, but also at all places on the earth's surface, unless we except the poles; for the diurnal course of the sun on these dates coincides with the celestial equator, which, as shown in Art. **44**, intersects the horizon of every place in the east and west points.

Subsequently to March 21 the sun rises and sets north of the east and west points upon an equatorial horizon, rising each successive day a little farther from the east, and setting a little farther from the west, until on June 21 it rises $23\frac{1}{2}°$ N. of E., and sets $23\frac{1}{2}°$ N. of W. After this it begins to return towards the east and the west points when rising and setting.

Subsequently to September 21 the sun rises S. of E. and sets S. of W. upon an equatorial horizon, until, on December 21, it has attained a distance of $23\frac{1}{2}°$ in these directions; after which, in the course of the succeeding three months, it returns to the east and west points once more, reaching them on September 21.

Upon March 21 and September 21 the sun is vertical, or in the zenith, at noon, for every situation upon the equator. From March 21 to September 21 it culminates, or comes to its noon position north of the zenith; and during the remainder of the year south of the zenith, attaining its greatest distance from the zenith, or $23\frac{1}{2}°$ at the times of the solstices. It then returns towards the zenith, reaching it at the time of either equinox.

79. The horizon of a place between the equator and the

poles (see Fig. 8, page 18) divides the equator only, of all the circles of declination, into two equal parts: therefore one-half of the sun's diurnal course is described above it only upon March 21 and September 21. If the place is north of the equator, northern circles of declination (and here we need only consider those to which the sun's course is confined, or which extend as far as the Tropic of Cancer) have their longer arc above the horizon, and shorter below it; and southern circles have their shorter arc above the horizon, and longer below it. When, therefore, the sun is north of the equator, the longer arcs are described by the sun during the day, and the day is more than twelve hours long; and when south of the equator, the shorter arcs are described, and day is less than twelve hours long. The reverse is the case if the place is south of the equator. The greater the distance from the equator, the greater the difference between the length of the two arcs into which a circle of declination is divided by the horizon; hence the greater the contrast between the length of the day and the night.

The more oblique the sphere, or the greater the latitude of the place, the more does its horizon differ in direction from that of the sun's motion in declination: hence the longer the distance measured upon the horizon which corresponds to a change of a given number of degrees in declination. In high latitudes the sun must therefore rise and set at a more rapid rate of advance along the horizon, and also approach more nearly to its northern and southern points. This rate of advance is nevertheless affected by the sun's rate of movement between the tropics, being considerably slower about the time of either solstice than at the time of an equinox.

The horizon, whose inclination to the equator is $23\frac{1}{2}°$, has the sun within its northern or its southern point at the respective times of the solstices; so that sunrise and sunset must take place within every point of this horizon

during the year, and one diurnal circle be described above it at the summer solstice. This is the case at places upon the polar circles.

80. At places within the polar circles the sun rises and sets at every point upon their horizons during the year; passing along the horizon at a more rapid rate the nearer the place is to the pole, and reaching the north or the south point *previously* to the time of a solstice. The *time* previously depends upon the distance of the given place from the polar circle, being greater with an increase of latitude. As the latitude increases, the greater, therefore, must be the number of entire diurnal circles which the sun describes continuously above the horizon during the year; and this agrees also with the increase in the continuance of day in this direction (see Art. **73**). The angle between these circles and the horizon diminishes towards the poles, until, at the poles, a difference of direction between the two ceases altogether, and the sun moves either in the horizon, or in a direction parallel to the horizon.

The rate at which the sun's diurnal circles ascend above the horizon, or descend towards it, within the polar regions (not now including the poles), depends upon the position of the sun within the ecliptic when describing them. If the day is two months or less, the sun is, during that time, describing an arc of the ecliptic nearly parallel to the equator, and moves northward or southward, therefore, at its slowest rate. When the day is a longer one, the sun leaves and returns to the horizon at its most rapid rate, or nearly so, during the former and the latter portion of it.

81. As an instance of the variety which the sun's diurnal circuits exhibit in the frigid zones, let us follow the sun's course at Spitzbergen for a year, beginning with the dawn succeeding a period of continuous night.

The sun appears in the southern point of the horizon upon February 21, and immediately sets without an intervening

course. The next day it describes a small arc, the next a longer one, and so on, until it rises in the east and sets in the west, having moved, both in rising and in setting, through a quarter of the horizon in coming to these equinoctial points. It now culminates 10° above the horizon. Subsequently to March 21 it describes arcs increasing in length until April 21, when its whole circuit is brought above the horizon, and so remains, rising higher and higher, until the time of the summer solstice. At this time the sun comes to the meridian of Spitzbergen at a distance of 35° above the south point of the horizon, and 13° above the north; the difference between these numbers (or 22°) showing the obliquity of its diurnal circles to the horizon of Spitzbergen. After this date the sun begins slowly to descend, until it sinks below the northern point of the horizon for a moment on August 21; after which it describes arcs gradually decreasing in length until it has left the visible heavens altogether upon October 21.

82. The zenith distance of the sun at noon for any given place north of the equator is equal to the difference between the latitude of the place and the sun's declination, if the latter is north declination; or to their sum, if it is south declination. The meridian altitude of the sun is always equal to the difference between its zenith distance and 90°. The reason for these rules should be found by the learner; and he should also derive a corresponding rule for places in the southern hemisphere. Thus, when vertical at the equator, the sun culminates 20° from the zenith, or 70° above the horizon, at the latitude of 20° N. or S., towards the southern point of the horizon at the former latitude, and northern at the latter. When vertical at the Tropic of Capricorn, its zenith distance is $23\frac{1}{2}$° at the equator, $33\frac{1}{2}$° upon the 10th northern parallel, $67\frac{1}{2}$° at the south pole, and so on.

83. Whenever the sun is vertical at a latitude north of a

given place, it culminates at a point of the meridian north of the horizon of that place; whenever it is vertical at a latitude south of a given place, it culminates south of the horizon of the place. It therefore culminates both upon the north and the south sides of the zenith at places within the torrid zones, but only upon one side of it at places within the temperate zones; namely, always towards the southern point of the horizon north of the Tropic of Cancer, and always towards the northern point of the horizon south of the Tropic of Capricorn.

Beyond the torrid zone the sun culminates at its extreme zenith distances at the times of the solstices; occupying its nearest position to the zenith at noonday of the summer solstice, and its farthest position from the zenith at noonday of the winter solstice. Within the torrid zone it culminates at its farthest position from the zenith at the time of the winter solstice; this being December 21 at places north of the equator, and June 21 at places south of the equator.

MEASUREMENT OF TIME.

84. Any series of events which take place at equal intervals of time may be employed as a measure of time. Thus the flowing of sand in the hour-glass, the vibrating of a pendulum, and the revolution of a star, have been severally used for this purpose. But the great standard of time is the period of the revolution of the earth on its axis, which, by the most exact observations, is found to be always the same.

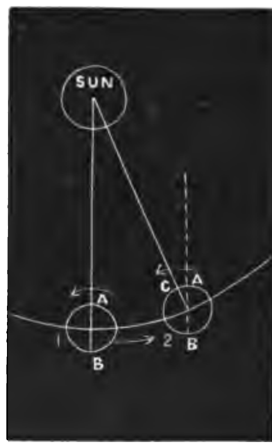
85. The passage of a heavenly body across the meridian of an observer is called the *transit* of the body: the transit nearer the zenith of the observer is the *upper* transit; that more remote from his zenith is the *lower* transit.

86. A *sidereal day* is the interval of time between two successive upper transits of a star, or of any fixed point of the celestial sphere over the same meridian. The transits

of the vernal equinox (see Art. 54) are always employed to mark the beginning and end of the sidereal day.

87. A *solar day* is the interval of time between two successive upper transits of the sun over the same meridian. Had the earth only a rotation on its axis, so that the sun was stationary in the heavens like a fixed star, the solar and the sidereal days would be equal. While, however, the diurnal motion of the earth is performed once, its motion in its orbit carries it eastward nearly 1°: consequently it must perform 1° more than a rotation before the same meridian returns to the sun, or between two successive upper transits of the sun. Thus, in the figure, the meridian A B, which is in conjunction with the sun in the position of the earth marked 1, differs from conjunction with the sun by the arc C A after the earth has performed exactly one rotation, and reached the position marked 2. Therefore the solar day must exceed the sidereal by the time required to rotate through the arc C A, which, as we have said, is about 1°, so that the solar day is about 4 minutes longer than the sidereal day. In other words, if the sun and a fixed star cross the meridian together, at their next transits the sun will cross the meridian about 4 minutes behind the star. When this has gone on for a whole year, the sun will have fallen behind the star by a whole circumference of the heavens; that is, the sun will have made fewer diurnal revolutions by one than the star. Thus the number of solar days in the year must be one less than the number of sidereal days.

Fig. 13.



88. The solar days, however, do not always differ from the sidereal by precisely the same amount; since, owing to the unequal motion of the sun in the ecliptic, these days are not constantly of the same length. Time, as measured by the sun, is called *apparent* time. *Mean* time is time reckoned by the *average* length of all the solar days throughout the year: thus the *mean solar day* is the average length of the solar day for the whole year. This period constitutes the *civil* day of twenty-four hours, beginning at midnight, or when the sun is on the meridian at its lower transit. It is divided into two periods of twelve hours each, from the lower to the upper transit (midnight to noon), and from the upper to the lower (noon to midnight). The *astronomical* day is the solar day (apparent or mean) counted through the whole twenty-four hours instead of by periods of twelve hours each, and begins at noon.

89. The interval by which apparent time differs from mean time is called the *equation of time*. The sun's change of right ascension is sometimes faster than if it moved on the equator, and sometimes slower: therefore the equation of time must sometimes be added to apparent time, and sometimes subtracted from it, to give the mean time. Its greatest additive value is about 14½ minutes, and occurs about February 11; and its greatest subtractive value is about 16¼ minutes, and occurs about November 3. The equation of time is zero, or mean and true time are the same four times in the year; viz., about April 15, June 15, September 1, and December 24.

Local time is the time of day (solar or sidereal) on any given meridian at any instant. Since the beginning of the day is determined by the transit across the meridian of the place of a body (sun or star) which has an apparent diurnal motion at the rate of 15° per hour, it follows that the local time at two places situated on different meridians must differ for the same absolute instant of time, and that

a difference of 15° in longitude must correspond to a difference of one hour in time. And, since the apparent motion of the sun is from east to west through the heavens, it follows that the local time is later at the more easterly of the two meridians. Hence a watch or chronometer, which is set to the time of any meridian, will appear to *gain* if carried to the *west*, and to *lose* if carried to the *east;* the amount gained or lost in any case being equal to the difference in longitude of the two places reduced to time. For example: if a watch keeping Boston time is taken to New York, it will be found to be about 12 minutes fast as compared with New-York time. This indicates that the difference in longitude of the two places is about 3°, or that New York is about 3° west of Boston in longitude. This example illustrates the principle by which the longitudes of places are actually ascertained.

THE SEASONS.

90. The perpetually recurring changes of the seasons, modifying the organization and distribution, as well as affecting in numberless ways the welfare, of all living things on the earth, may be easily shown to result from the obliquity of the ecliptic, or, what comes to the same thing, the inclined position of the earth's axis with reference to the plane of the ecliptic. From this, as a primary cause, it follows, as we have seen, first, that the length of time that the sun remains above the horizon of any place varies during the year; secondly, that the meridian or noon altitude attained by the sun undergoes corresponding variations. Now, these two circumstances, operating as secondary causes, regulate the supply of heat, which, along with the light, the earth's surface receives from the sun; and the variations in this supply of heat determine the changes of the seasons.

91. The effect of the duration of the day upon the supply of heat is quite obvious. Whenever the sun is above the

horizon of a place, that place is receiving heat from it; when below, it is losing heat by a process called *radiation*, illustrated every time a teakettle is removed from the fire, or a person goes out of a warm room into the cold air. The longer the day, therefore, and the shorter the night, the greater the supply of heat from the sun by day, and the less the amount lost by radiation during the night. So far, then, as the mere length of the day is concerned, it is clear that the influence of the sun in raising the temperature of the surface of the earth at any place is greatest when the days are longest (i. e., in June, for the northern hemisphere), and is least when the days are shortest, or at the time of the winter solstice.

This cause must more sensibly affect places far removed from the equator, because at such places the days are longer and the nights shorter than in the torrid zone. By the operation of this cause, the solar heat accumulates there so much during the longest days of summer, that the temperature rises to a higher degree than is often experienced in much lower latitudes.

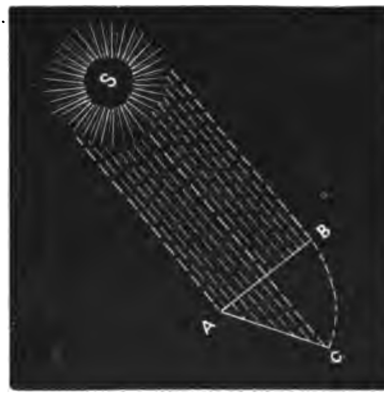
92. But, in general, the second cause — the greater or less obliquity of the sun's rays — has much more influence in changing the temperature of the earth's surface than the mere length of time that the sun is above the horizon.

"The higher the sun ascends above the horizon, the more directly his rays fall upon the earth; and their heating power is rapidly augmented as they approach a perpendicular direction. When the sun is nearly overhead, his rays strike us with far greater force than when they meet us obliquely; and the earth absorbs a far greater number of those rays of heat which strike it perpendicularly than of those which meet it in a slanting direction. When the sun is near the horizon, his rays merely glance along the ground; and many of them, before they reach it, are absorbed and dispersed in passing through the atmosphere. Those who have felt only the oblique solar rays, as they

fall upon objects in the high latitudes, have a very inadequate idea of the power of a vertical, noonday sun, as felt in the region of the equator."

The exact manner in which the inclination of the surface of the earth to the sun's rays modifies the supply of heat received is illustrated in Fig. 14. Let A B represent a portion of the earth's surface upon which the rays of the sun (S) fall vertically, and A C an equal surface upon which the rays fall obliquely; and suppose, further, that the angle B A C is such that the ray S C bisects A B. Now, as shown in the figure, the rays impinging on one-half of the surface A B would be spread out over the entire surface A C, so that this surface would receive only one-half as much heat as was received by the equal surface A B.

Fig. 14.



93. Both of these causes co-operate in the temperate zones to elevate the temperature of the earth's surface; for, when the days are the longest, the meridian altitude of the sun is the greatest. The greatest temperature of a place, however, is not at the time of the summer solstice, but about a month later, because the amount of heat received by the earth during the day continues, for some time after the solstice, to exceed the amount radiated by night: consequently, heat must accumulate until these amounts become equal. Afterwards, the decrease being greater than the increase, the heat will diminish. For a similar reason, the coldest period occurs some time after the winter solstice.

94. Since the earth is not always at the same distance from the sun, but is nearest the sun at the *perihelion* point, and farthest at the *aphelion* point, it might be supposed that this circumstance would have much to do with producing the changes of the seasons. The nearer the earth is to the sun, the greater must be the intensity of the solar heat, and *vice versa*. But it can be shown, that by reason of the small amount of the variation in distance, and the unequal rate at which the earth moves in its orbit, this change of distance has but a very trifling influence upon the amount and distribution of light and heat upon the earth.

95. The seasons vary much in character with the different *zones* upon the earth's surface.

In the *north temperate zone*, the year is divided into the four seasons,—*spring*, *summer*, *autumn*, and *winter*. Astronomically speaking, these begin respectively at the following dates: Vernal equinox, summer solstice, autumnal equinox, winter solstice. Approximately, these dates are March 21, June 21, September 21, December 21; but the precise dates differ somewhat from these, owing to the unequal rate of the motion of the earth round the sun, and they also vary within small limits from year to year.

For the year 1872, the exact dates (in mean solar time) of the equinoxes and solstices are,—

Vernal equinox, March 20, 7 h. 6 m. A.M.
Summer solstice, June 21, 3 h. 41 m. A.M.
Autumnal equinox, September, 22, 6 h. 2 m. P.M.
Winter solstice, December 21, 0 h. 2 m. P.M.

Thus winter is the shortest season, and summer the longest, while spring is longer than autumn. Spring and summer, taken together, are about eight days longer than autumn and winter combined.

To the *south temperate zone* what has been said of the north temperate will apply, if we interchange the equinoxes, the solstices, the terms winter and summer, and the terms spring and autumn.

In the *torrid zone*, the motion of the sun with respect to the zenith is different from what it is in the temperate zones, since it crosses the meridian to the south of the zenith during part of the year, and to the north of it during the remainder of the year. The variations in the length of the day are less than at any place in the temperate zones, and the average noon altitude of the sun during the year is greater. The torrid zone is, therefore, a region of great heat throughout the year, with comparatively little difference (so far as temperature is concerned) between opposite seasons.

The *frigid zones* are regions of low temperature on the average throughout the year, and of excessive winter cold, contrasted by a brief season of extreme summer heat.

96. Finally, it should be noticed that the temperature of a place is influenced very much by local and temporary causes, as well as by the intensity and duration of the sun's heat.

"First, the *elevation* of a country above the level of the sea has a great influence upon its climate. Elevated districts of country, even in the torrid zone, often enjoy the most agreeable climate in the world. The cold of the upper regions of the atmosphere modifies and tempers the solar heat, so as to give a most delightful softness; while the uniformity of temperature excludes those sudden and excessive changes which are often experienced in less favored climes. In ascending certain high mountains situated within the torrid zone, the traveller passes in a short time through every variety of climate, from the most oppressive and sultry heat to the soft and balmy air of spring, which again is succeeded by the cooler breezes of autumn, and then by the severest frosts of winter. A corresponding difference is seen in the products of the vegetable kingdom. While winter reigns on the summit of the mountain, its central regions may be encircled with the verdure of spring, and its base with the flowers and

fruits of summer. Secondly, the proximity of the *ocean* also has a great effect to equalize the temperature of a place. As the ocean changes its temperature during the year much less than the land, it becomes a source of warmth to contiguous countries in winter, and a fountain of cool breezes in summer. Thirdly, the relative *humidity* or *dryness* of the atmosphere of a place is of great importance in regard to its effects on the animal system. A dry air of ninety degrees is not so insupportable as a humid air of eighty degrees; and it may be asserted as a general principle, that a hot and humid atmosphere is unhealthy, although a hot air, when dry, may be very salubrious. In a warm atmosphere which is dry, the evaporation of moisture from the surface of the body is rapid, and its cooling influence affords a most striking relief to an intense heat without; but, when the surrounding atmosphere is already filled with moisture, no such evaporation takes place from the surface of the skin, and no such refreshing effects are experienced from this cause. Moisture collects on the skin; a sultry, oppressive sensation is felt; and chills and fevers are usually in the train." (*a*)

TWILIGHT.

97. Besides being necessary for respiration, the atmosphere contributes to our welfare in another way almost equally important. The molecules of which it is composed reflect in every direction a portion of the light which they receive from the sun, and these numerous reflections produce the *diffused light* by means of which we are able to see objects by day in the absence of the direct rays of the sun. If there were no atmosphere, every place which was not directly illuminated by the sun, or which did not receive rays reflected from the ground or other objects, would be plunged in complete darkness. The blue color

---

(*a*) Olmstead's Letters on Astronomy, pp. 124–26.

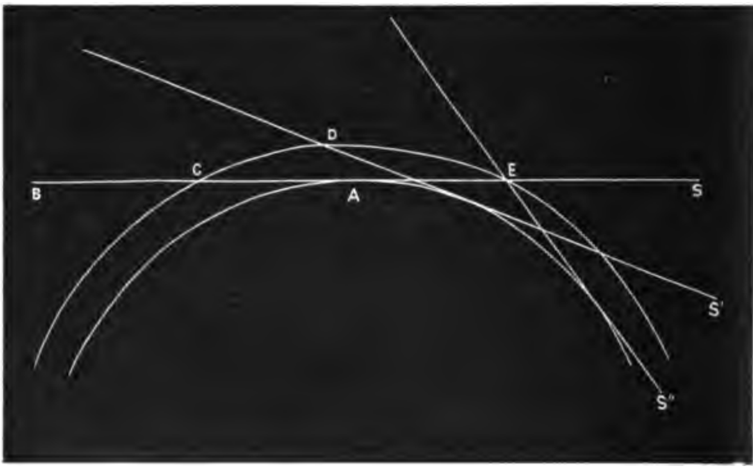
of the sky, which is nothing but the color of the air seen through a thickness of many miles, would disappear, and the heavens at mid-day would be uniformly and intensely black, save only at the spots occupied by the sun, moon, and stars. Moreover, the phenomenon known as twilight would have no existence. The instant the sun disappeared from view, the darkness of midnight would prevail, and would continue until abruptly brought to an end by the sun's reappearance above the horizon.

The season of twilight which we enjoy at the dawn and the close of day is due to the power of the atmosphere to reflect and scatter the solar rays which it receives. The earth's atmosphere forms a shell fifty miles or thereabouts in thickness around the earth: hence those rays from the sun which are nearly tangent to the earth's surface must pass on into the higher regions of the atmosphere beyond, and from these they are reflected into portions of the atmosphere which would otherwise receive no light at all. This reflected light, properly speaking, constitutes *twilight* (doubtful light, as the word means in the original Anglo-Saxon). At any given place, when the sun is just setting or rising, the entire atmosphere which lies above the plane of the horizon is directly illuminated by the sun. After sunset, the portion of the atmosphere directly illuminated constantly diminishes, and with it also the quantity of light reflected to the place in question, until at last no sunlight enters directly the region of the atmosphere referred to, when twilight is said to be at an end. In the morning, similar changes in the amount of light received occur in an inverse order.

In Fig. 15, let A represent a given place, at which the sun, S, is in the act of setting; the ray, S B, representing a plane of rays tangent to the earth at A, and coinciding with the plane of the horizon at A, and therefore including above it the entire visible sky. In this case, A receives light from the whole reflecting atmosphere, C D E: twilight

is, in fact, just beginning. In the position of the sun marked S′, A receives light from only the portion D E of the atmosphere. The degree of illumination at A depends

Fig. 15.



on the size of this portion, and therefore grows less as the sun recedes from the horizon. At S″ the sun's rays graze the exterior limit of the section C D E, and twilight fades completely away.

Twilight, astronomically considered, is generally said to continue while the sun is within 18° of the horizon, measuring in the direction of a vertical circle (see vertical circle, Art. 43); but this distance really varies from 15° to 20°. Heat tends to lessen the limit, and cold to increase it.

The time which the sun occupies in moving to a distance of 18° from a given horizon depends both upon the angle between the circle of declination which the sun is describing and the horizon of the place, and upon the size of this circle of declination. The effect of a change of the angle may be illustrated by supposing two hoops to cross

each other at various angles. Suppose, now, that we find a point on one of the hoops (representing the sun's course), which, in the several positions, is at a given distance from the other hoop (which represents the horizon): evidently, the less the angle between the hoops, the greater the distance of this point from the intersection of the hoops.

The only horizons for which the sun's entire diurnal course is at any time coincident with a vertical circle are those of places upon the equator at the times of the equinoxes. The shortest period of twilight, therefore, is experienced at the equator on March 21 and September 21, and is about 1 hour and 12 minutes. At all other times the sun's course is upon a circle of declination parallel to, but smaller than, the equator. This increases slightly the duration of twilight for places on the equator; the longest twilight occurring at the times of the solstices, and being about 1 hour and 19 minutes.

The greater the latitude of a place, the greater the obliquity of its horizon to the sun's diurnal course: therefore there is a constant increase in the duration of twilight as we proceed from the equator towards the pole. There is also a constant change in the duration of twilight *at the same place* during the year, this change attending the changes of points on the horizon in which the sun rises and sets.

The varying angle at which the sun proceeds with respect to a given horizon, during the year, is very simply shown upon the globe accompanying this manual by adjusting the ring arrangement upon this globe to any given place, as Boston, and then comparing the angles which the brass horizon forms upon the north with the equator, and one or two small circles, as the tropics.

The direction of the sun's diurnal motion at rising and setting for places north of the equator most nearly coincides with that of a vertical circle on March 6, or when the sun describes a parallel about 6° south of the equator:

therefore, at this time, places in north latitude have their shortest twilight. On the other hand, the direction of the sun's motion makes the smallest angle with the horizon at the time of the summer solstice: therefore places in north latitude have their longest twilight upon June 21. Places in south latitude have their shortest twilight upon April 6, and their longest upon December 21.

When a parallel, having an arc in day, extends into the unilluminated hemisphere of the earth's surface for a distance of more than 18° beyond the day-circle, it has morning and evening twilight. When it extends only 18°, or less, it has a twilight continuing through the night, or lasting from sunset to sunrise. When the whole parallel is embraced within the 18°, it has a period of continual twilight. Stockholm has a twilight lasting from sunset to sunrise for a space of 4 months. The 85th parallel has a continuous twilight of about 28 days.

Astronomical twilight, above considered, is much longer than what is ordinarily regarded as twilight.

DESCRIPTION OF THE GLOBE.

THE stand of this globe supports upon its upper surface a metal disk, fitted to revolve about a vertical axis, and, by its revolution, to represent the progress of the earth in its orbit, and of the sun in the ecliptic. Around this disk are marked, in two concentric circles, the names of the calendar months, (*a*) and the signs of the ecliptic; each month and sign being divided into 30 equal parts by means of the subdivisions around the edge of the cylinder, these parts representing days in the months, and degrees in the signs. These subdivisions are numbered at every 10th day and degree; the outer numbers referring to days, and the inner to degrees. An index pointing towards the disk, upon a level with its upper surface, records the passage of its subdivisions as it revolves. This index is called the *calendar index*, and the disk the *calendar disk*.

Attached to the calendar disk, and making with it an angle of 66½°, is a metal rod, or axis, representing the axis of the earth. Upon this axis a common terrestrial globe is mounted, and turns freely. The axis is not fastened to

(*a*) These months are uniformly divided into 30 days each; it being necesary to have the dates of the equinoxes and solstices exactly 90° apart upon the calendar disk, in order that the solar index shall be opposite the equator or a tropic when these dates are brought to the calendar index.

the centre of the disk, but to such a point that the centre of the globe shall always remain vertically over the centre of the disk, while the latter revolves about a vertical axis. In the course of one revolution of the disk, the axis evidently describes or generates the surface of a cone whose vertex coincides with the centre of the globe. The body of the globe is thus made to occupy the same position with respect to the stand at all times; and yet, by the conical motion above described, its axis, together with its surface, is shifted with respect to any fixed line passing through its centre, through a maximum distance of twice 23½ degrees during each semi-revolution of the disk.

Directly above the calendar index is another index, pointing towards the centre of the globe, called the *solar index*. It represents the sun, or, more properly, the central ray proceeding from the sun; so that the position upon the surface of the globe to which it points at any time represents the place upon the earth's surface at which the sun is vertical at that time.

The divisions of day, night, and twilight, upon the earth's surface, are represented upon this globe by means of two brass circles (these circles being cut away beneath, in order to afford passage to the axis of the globe) rising from a semicircular support, which, with the circles, admits of removal from the globe-stand. When adjusted to the globe-stand, the larger circle is so situated that every point of it is 90° distant from the solar index: it divides the day-side of the globe from its night-side, and is called the *day-circle*. The smaller circle includes between it and the larger one the section embraced by twilight upon the earth's surface, and divides twilight from dark-night: it is called the *twilight-circle*, and is situated at a distance of 18° measured upon a great circle from the day-circle.

From this method of mounting, it follows that the globe has two distinct motions; namely, a revolution along with the disk about a vertical axis, and a rotation alone about

an axis which always makes with the plane of the disk the angle of 66½°. The former motion represents the yearly motion of the earth, and the latter its daily motion; the movement in both cases being made from left to right. As the disk is revolved, the rod representing the earth's axis assumes, in the course of one revolution, every position with respect to the solar index, or rather with respect to the line of direction of this index, that is actually assumed by the earth's axis relatively to the line joining the centres of the sun and the earth during the annual revolution of the earth around the sun. The solar index describes the passage of the sun between the tropics, marking out the entire circle of the ecliptic in the course of the revolution. The brass circles meantime indicate the changes of length in day, night, and twilight; these changes being more fully illustrated by simply rotating the globe on its axis for different times in the year.

The calendar index always points to the day of the year for which the solar index and brass circles are in position. Small knobs projecting from the outer surface of the calendar disk serve to manipulate it. A nut on the under side of the globe-stand may be screwed up, should the disk move too easily.

A ring arrangement consisting of a ring called the *brass horizon*, and a semi-ring called the *brass meridian*, is employed to represent the horizon and meridian of any given place. It is fitted to position on the globe for any place by adjusting the perforation at the middle of the semi-ring to the place, with the brass meridian passing in the direction of the meridian of the place. The globe being now revolved upon its axis, the solar index describes the daily course of the sun (if the sun rises and sets upon the given day) by moving from side to side of the brass horizon, crossing the brass meridian at the time of noon.

When the ring arrangement is adjusted to a given place, the extremity of the brass meridian north of the equator

represents the northern point of the horizon, and that south of it the southern. The east and west positions on the brass horizon are each indicated by a black zero (o); the former being upon the right of the brass meridian, and the latter upon the left. Both the brass meridian and horizon are graduated upon their outer surfaces.

When the ring arrangement of this globe is to be brought into use, the brass circles must first be removed; which is done by drawing upon the knob which projects from their circular base. When the brass circles are required for use, the ring arrangement must first be lifted from the globe; this being easily done when the circles are away. The larger brass circle is graduated upon its dayside, its degrees being numbered at intervals of ten, and corresponding at these intervals with parallels of latitude upon the globe, when this is in position for March 21.

In order to measure in degrees arcs of any great circle on the globe, as, for example, vertical circles, or the distance of any two places from each other, a cloth quadrant graduated to degrees, and called the *altitude quadrant*, is provided. This quadrant may be threaded into the perforation of the ring arrangement whenever required for finding the sun's azimuth, altitude, &c.

PART II.

PROBLEMS UPON THE GLOBE.

N. B. — In practising upon the globe, set its stand so that the side upon which the solar index is situated shall be turned towards you. Problems XVI., XXXVI., and XXXVII. call into use the ring arrangement. For the remainder, have this removed, and the brass circles in place.

PROBLEMS UPON LATITUDE, LONGITUDE, AND DISTANCE.

PROBLEM I.

To find the Latitude and Longitude of a given Place.

1. Bring March 21 to the calendar index.

2. Bring the given place to the graduated edge of the day-circle, upon the east.

3. Read off the latitude upon the day-circle, over the place; and the longitude upon the equator, where the graduated edge of the day-circle cuts it upon the east.

Exercises. — Find the latitude and longitude of Washington.

Ans. — Lat. 39° N., long. 77° W.

Find the latitude and longitude of Amsterdam, Berlin, Paris, Boston, St. Louis, Valparaiso.

PROBLEM II.

Given the Latitude and Longitude, to find the Place.

1. Bring March 21 to the calendar index.

2. Bring the given degree of longitude to the graduated edge of the day-circle, upon the east.

3. Look for the given latitude upon the side of the day-circle with the given longitude: the place will be under this latitude.

Exercises. — Find the place whose longitude is 68° E., and latitude 58° N.

Ans. — Tobolsk.

Find those places whose latitudes and longitudes are as follows; namely, 52° N. lat. and 5° E. long., 31° N. lat. and 30° E. long., 52° N. lat. and 13° E. long., 42° N. lat. and 70° W. long., 6° N. lat. and 52° W. long., 12° S. lat. and 76° W. long.

PROBLEM III.

To find all those Places that are in the same Latitude or Longitude with a given Place.

1. Bring March 21 to the calendar index.

2. Bring the given place to the graduated edge of the day-circle, upon the east; and all those places under the same edge, as far as the poles, are in the same longitude.

3. Turn the globe upon its axis; and all those places passing under the latitude of the given place, as marked upon the day-circle, are in the same latitude.

Exercises. — Find all those places that are in the same, or nearly the same, latitude or longitude as Cairo.

Ans. — Alexandria, Odessa, and St. Petersburg are nearly in the same longitude; Delhi, Houston, Mobile, and Tallahassee are nearly in the same latitude.

Find all those places that are in the same, or nearly the same, latitude or longitude as Paris, Constantinople, London, Lima, San Francisco, Montreal, New York.

PROBLEM IV.

Given two Places, to find their Difference of Latitude.

FIRST METHOD.

1. Find the latitude of both places by Problem I.
2. Count the degrees between the two latitudes as marked upon the day-circle.

SECOND METHOD.

1. Find the latitude of both places by Problem I.
2. Add the two latitudes if upon opposite sides of the equator; subtract the smaller from the greater if upon the same side.

Exercises. — Find the difference of latitude between Guatemala and Stockholm.

Ans. — 45°.

Find the difference of latitude between Philadelphia and New Orleans, Paris and Madrid, Quito and Calcutta, Dublin and Baltimore, Havana and Batavia, Jerusalem and Stockholm.

PROBLEM V.

Given two Places, to find their Difference of Longitude.

FIRST METHOD.

1. Find the longitude of both places by Problem I.
2. Count the degrees between them as marked upon the equator, reckoning upon the arc which measures the shorter distance between them.

SECOND METHOD.

1. Find the longitude of both places by Problem I.

2. Add the two longitudes if upon opposite sides of the meridian of Greenwich, subtracting their sum from 360 if it exceed 180; subtract the smaller from the greater if upon the same side.

Exercises.—Find the difference of longitude between Boston and Cairo.

Ans.—103°.

Find the difference of longitude between Pekin and Aden, Bombay and Lisbon, Madras and San Francisco, Nankin and Mobile, Rio Janeiro and Gondar, Damascus and Cork.

PROBLEM VI.

To find the Antœci, Periœci, and Antipodes of a given Place.

Note.—The antœci are the inhabitants of the earth who live in the same longitude, but in opposite latitudes,—the one part as far north of the equator as the other south.

The periœci are the inhabitants of the earth who live in the same latitude, but in opposite longitudes.

The antipodes are the inhabitants of the earth who live diametrically opposite to each other.

1. Find the latitude of the given place by Problem I., and follow along the day-circle to the same latitude in the opposite hemisphere for the antœci.

2. Find the longitude of the given place by Problem I., and follow along the parallel of the place until it again intersects the day-circle for the periœci.

3. Find the antœci of the given place, and follow along the parallel of the antœci until this parallel again intersects the day-circle for the antipodes.

Or find the periœci of the given place, and follow

along the day-circle to the same latitude in the opposite hemisphere.

Note 1. — The learner should employ both methods of finding the antipodes of a place, and thus satisfy himself that they both give the same result.

Note 2. — Those places situated on the equator have no antœci, and their periœci are their antipodes. The poles have no periœci, and their antœci are their antipodes.

Exercises. — Find the antœci, periœci, and antipodes of Canton.

Ans. — The antœci are in the north-western part of Australia, near Sharks Bay; the periœci are midway between the Bermudas and the Caribbees; and the antipodes are in the northern part of the Argentine Republic, between the Rivers Grande and Salado.

Find the antœci, periœci, and antipodes of Mecca, Cape Horn, Valparaiso, Lima, Dresden, Manilla.

PROBLEM VII.

To find the Distance between two Places.

1. Lay the edge of the altitude quadrant over the two places, so that the point marked zero (0) may be over one of them: the number of degrees over the other place will give the number of degrees that they are apart.

2. Multiply the number of degrees by 60 to obtain the distance in geographical miles; by 69.1 to obtain it in statute miles. (*a*)

Note. — If the two places are upon the equator or the same meridian, the distance between them can be estimated upon the circle upon which they lie.

(*a*) A degree of a great circle of the earth considered as a sphere is divided into 60 *geographical* miles, and contains 69.1 common or *statute* miles.

Exercises.—Find the distance in geographical miles between London and Botany Bay. (*a*)

Ans.—9,240 miles.

Find the distance in geographical miles between Washington and London, Sitka and Nankin, Manilla and Aden; in statute miles between Boston and New Orleans, Dublin and Cincinnati, Cayenne and Valparaiso.

PROBLEM VIII.

Given the Latitude or Longitude of a Place, and its Distance from a given Place, to find the Place whose Latitude or Longitude is given.

1. Reduce the given distance to degrees by allowing 60 geographical, or 69.1 statute miles to a degree.

2. Place zero (0), on the quadrant, over the given place.

3. Direct the quadrant towards the east or the west, according to the direction of the required place from the given place; and lay the degree upon it, equalling the given distance, over the given latitude or longitude: beneath it will be found the required place.

Example.—Find the place in latitude 32° N. which is 2,750 geographical miles south-west from the Lizard, in England.

Ans. The Bermudas.

Find the place in latitude 60° N. which is 1,320 statute miles north-east from London; in longitude 118° W. which is 2,766 statute miles south-west from Boston; in longitude 10° E. which is 3,596 statute miles north-east from Washington; upon the equator which is 3,600 geographical

(*a*) When the distance between the two places exceeds the length of the quadrant, the ring arrangement may be used instead.

miles south-west from Cape Verde; in latitude 10° S. which is 4,710 miles south-west from Hawaii; in longitude 135° W. which is 3,420 geographical miles north-east from Jeddo.

PROBLEM IX.

To find the Length of a Degree of Longitude corresponding to a given Latitude.

1. Ascertain how many degrees upon the altitude quadrant are equal to 15° of longitude at the given latitude.

2. Reduce this number of degrees to miles by direction 2, Problem VII.; and divide the product by 15, the number of degrees measured at the given latitude. Or,—

3. Reduce this number of degrees to geographical miles by multiplying by 4, to statute miles by multiplying by 4.6.

Example. — Find how many geographical miles make a degree of longitude at the latitude of Philadelphia.

Ans. — 48.

Find how many miles, either geographical or statute, make a degree of longitude upon the parallels of 15° N., 30° N., 60° N., upon the parallels of Boston, London, Paris.

Note. — The number of miles in a degree of longitude upon a given parallel is proportional to the rate at which one situated upon the parallel is carried from west to east by the revolution of the earth upon its axis.

N. B. — In working the three preceding problems, the ring arrangement may be employed, in case a quadrant is not at hand; or a thread will serve the purpose very well, it being applied to the equator to reduce any required portion upon it to degrees.

PROBLEMS UPON TIME.

PROBLEM X.

To bring a given Place into a given Hour of the Day or Night.

FIRST METHOD.

1. Bring the given place into 12 o'clock, or noon, by bringing its meridian to the solar index.

2. If the given time is later than 12, turn the globe upon its axis towards the east until as many intervals of longitude (of 15° each) have passed the solar index as the time is past 12, reckoned in hours.

3. If the given time is earlier than 12, turn the globe upon its axis towards the west until as many intervals of longitude are passed by the solar index as the time is before 12, reckoned in hours.

SECOND METHOD.

1. Bring the meridian of the given place to the solar index.

2. Set the hour-index to 12.

3. If the given time is later, turn the globe upon its axis towards the east until the hour-index points to this time.

4. If the given time is earlier, turn the globe upon its axis towards the west until the hour-index points to this time.

Note. — When the day-circle divides the globe at the poles, every place upon a meridian may be brought into a given hour of the day or night; but this cannot be done upon parallels lying wholly upon the day-side or the night-side.

Exercises. — Bring New York into 4h. 20m. P. M.

Ans. — New York is brought into 4h. 20m. P. M. when its meridian is $4\frac{1}{3}$ intervals east of the solar index.

Bring Chicago into 2 A. M., Nashville into midnight, Mexico into 1 A. M., Lima into 6h. 20m. P. M., London into 3h. 40m. A. M., Constantinople into 11h. 10m. A. M.

PROBLEM XI.

Given the Difference of Longitude between two Places, to find their Difference of Time.

FIRST METHOD.

Reduce the difference of longitude to hours by dividing by 15, or to minutes by multiplying by 4.

SECOND METHOD.

1. Bring the solar index opposite the equator by bringing either March 21 or September 21 to the calendar index.
2. Bring the meridian of Greenwich to the solar index.
3. Turn the globe on its axis towards the east until the solar index has passed over as many degrees as are equal to the given difference of longitude. The number of intervals in these degrees (if there are 15 degrees in an interval) will be the number of hours in the required difference.

THIRD METHOD.

1. Bring the meridian of Greenwich to the solar index.
2. Set the hour-index to XII.
3. Turn the globe on its axis towards the east until the difference of longitude is passed by the solar index. The hour-index will now point to the required difference of time.

Exercises.— Find the difference of time between two places whose difference of longitude is 40°.

Ans.— 2 h. 40 m.

Find the difference of time, the difference of longitude being 10°, 124°, 50°, 67°, 90°, 84°.

PROBLEM XII.

Given the Difference of Time between two Places, to find their Difference of Longitude.

FIRST METHOD.

Reduce the difference of time to longitude by multiplying it, if given in hours, by 15; or dividing it, if given in minutes, by 4.

SECOND METHOD.

1. Bring the solar index opposite the equator by bringing either March 21 or September 21 to the calendar index.
2. Bring the meridian of Greenwich to the solar index.
3. Turn the globe on its axis either towards the east or the west, until the solar index has passed over as many intervals of longitude as are equal to the number of hours in the given difference of time. The degree of longitude opposite the solar index is the required difference of longitude.

THIRD METHOD.

1. Bring the meridian of Greenwich to the solar index.
2. Set the hour-index to XII.
3. Turn the globe on its axis towards the east until the given difference of time is passed by the hour-index. The degree of longitude opposite the solar index is the required difference of longitude.

Exercises. — Find the difference of longitude between two places whose difference of time is 2 h. 20 m.

Ans. 35°.

Find the difference of longitude, the difference of time being 4 h., 6 h. 30 m., 10 h., 16 h., 3 h. 8 m., 12 h., 16 h.

PROBLEM XIII.

Given two Places, to find their Difference of Time.

FIRST METHOD.

Find the difference of longitude between the two places by Problem V., then proceed as in Problem XI.

SECOND METHOD.

1. Bring the meridian of one of the places to the solar index, having the meridian of the other upon the west of it.

2. Turn the globe on its axis towards the east, and count the intervals of longitude that are passing while the meridian of the second place is brought opposite the solar index. This number is the number of hours in the required difference.

THIRD METHOD.

1. Bring the meridian of one of the places to the solar index, having the meridian of the other upon the west of it.

2. Set the hour-index to XII.

3. Turn the globe on its axis towards the east until the meridian of the second place is brought opposite the solar index. The hour-index will now point to the required difference.

Exercises. — Find the difference of time between Savannah and Sante Fé.

Ans. — 1 h. 40 m.

Find the difference of time between Alexandria and Damascus, Calais and Halifax, Bangor and Smyrna, Galveston and Ghent, Hamburg and Havana, Chicago and Portland.

PROBLEM XIV.

Given the Hour of the Day at a Place, to find all those Places on the Earth's Surface where it is then Noon, or any other given Hour.

FIRST METHOD.

1. Bring the given place into the given hour by Problem X. All places situated upon the semi-meridian opposite the solar index, or upon the one which bisects the day-side of the globe, are now in noon; all places situated on the semi-meridian which bisects the night-side of the globe are in midnight.

2. If the hour at the required places is before noon, the meridian upon which these places are situated will be found as many intervals west of the solar index as there are hours before noon.

3. If the hour at the required places is after noon, the meridian upon which these places are situated will be found as many intervals east of the solar index as there are hours after noon.

Note.—The required places must have the same longitude; that is, they must be found upon the half of a meridian which passes between the poles. If any portion of this semi-meridian crosses parallels lying wholly upon the day-side or the night-side of the globe, the hour at places upon this portion is the same as at places upon the remaining portion; but this hour shows the advance of the sun from due north or south within the sky (if the period is one of continuous day), rather than the advance of the day from noon or midnight. If the period is one of continuous night, the advance of the sun from due north or south, below the horizon, is shown.

SECOND METHOD.

1. Find the difference between the given time and the time at the required places, and reduce this difference to longitude by Problem XII.

2. If the hour at the required places is earlier than the hour at the given place, the required meridian will be found as many degrees west of the given place as are equal to the difference of longitude.

3. If the hour at the required places is later than the hour at the given place, the required meridian will be found as many degrees east of the given place as are equal to the difference of longitude.

THIRD METHOD.

1. Find the difference between the hour at the given place and the hour at the required places.

2. Bring the meridian of the given place to the solar index.

3. Set the hour-index to XII.

4. If the hour at the required places is earlier than the hour at the given place, turn the globe on its axis towards the east until the hour-index has passed over as many hours as are equal to the difference of time. If the hour at the required places is later than the hour at the given place, turn the globe on its axis towards the west until the hour-index has passed over as many hours as are equal to the difference of time; and in both cases the required places will be found upon the meridian opposite the solar index. (*a*)

(*a*) The use made of the solar index in the preceding method is convenient, but somewhat objectionable, because it places a meridian having any given time of forenoon or afternoon in the position of noon as this position is represented upon the globe.

Exercises.—When it is 12 M. at Boston, where is it 7 A.M.?

Ans.—At Prince Williams's Sound, and at the central islands of King George's group in the Pacific Ocean.

When it is 12 M. at London, where is it 8 A.M.? when 5 P.M. at Madrid, where is it noon? when 5h. 30m. A.M. at Pekin, where is it midnight? when 3 A.M. at Delhi, where is it 6 A.M.? when noon at Boston, where is it 1 A.M.? when 2 A.M. at Philadelphia, where is it 2 P.M.?

PROBLEM XV.

Given the Hour of the Day at a Place, to find the Hour at another Place. (*a*)

FIRST METHOD.

1. Find the difference of time between the two places by Problem XIII.

2. Add this difference to the given time, or subtract it from it, according as the required place is east or west of the given place.

SECOND METHOD.

1. Find the difference of longitude between the two places by Problem V.

2. Reduce this difference to time by Problem XI.; then proceed according to direction 2 of First Method.

THIRD METHOD.

Bring the given place into the given hour by Problem X. The distance of the meridian of the other place from the solar index will now indicate the required hour.

(*a*) The hour is the same at places whose longitude is the same.

Exercises. — Find the time at Rio Janeiro when it is noon at Madrid.

Ans. — 9h. 28m. A.M.

Find the time at Philadelphia when it is 8 A.M. at London, at Paris when it is 4 P.M. at Canton, at Boston when it is midnight at Leghorn, at New York when it is 10 A.M. at San Francisco, at Havana when it is 5 A.M. at Edinburgh, at Portland when it is 2h. 30m. A.M. at Quebec.

PROBLEMS UPON DAY AND NIGHT.

PROBLEM XVI.

To represent the Three Positions of the Sphere, — Right, Parallel, and Oblique.

1. Adjust the ring arrangement to a position on the equator for the right sphere.
2. Adjust the ring arrangement to any position between the equator and the poles for the oblique sphere.
3. Adjust the ring arrangement to the North Pole for the parallel sphere.

N. B. — See that the brass meridian is always set in the direction of a meridian of the globe. Be careful also, when changing the position of the ring arrangement, to lift it slightly, that it may rub upon the surface of the globe as little as possible.

PROBLEM XVII.

To find the Times of Sunrise and Sunset at a given Place on a given Day, and also the Lengths of the Day and of the Night. (*a*)

FIRST METHOD.

1. Bring the given day to the calendar index.

2. Look for the parallel upon which the given place is situated, and count the intervals of longitude upon this parallel, which are upon the day-side of the globe, for the length of the day.

3. Count the intervals of longitude upon the same parallel, which are upon the night-side of the globe, for the length of the night; or subtract the length of the day from 24 hours.

4. One-half the length of the day is the time of sunset, and one-half the length of the night is the time of sunrise.

SECOND METHOD.

1. Bring the given day to the calendar index.

2. Bring the meridian of the given place to the solar index.

3. Set the hour-index to XII.

4. Turn the globe on its axis towards the west until the given place is beneath the graduated edge of the day-circle, upon the left. The hour-index will now point to the time of sunrise.

5. Turn the globe on its axis towards the east until the given place is beneath the graduated edge of the day-circle, upon the right. The hour-index will now point to the time of sunset.

(*a*) The given place must be situated upon a parallel lying partly upon the day-side of the globe, and partly upon the night-side, in order to have the sun rise and set every day.

6. Twice the time of sunset gives the length of the day; twice the time of sunrise gives the length of the night.

Exercises. — Find the times of sunrise and sunset, and the lengths of the day and the night, at London, upon July 17.

Ans. — The sun rises at 4 o'clock, and sets at 8: length of day, 16 hours; length of night, 8 hours.

Find the times of sunrise and sunset, and the lengths of the day and the night, at Washington, May 1; London, August 15; New Orleans, July 10; Mexico, November 4; Cape Horn, February 5; Quito, May 1, October 6, December 21. (*a*)

N. B. — Whenever it is not convenient to find the length of day or night upon a parallel in the southern hemisphere, find this length upon the parallel corresponding to the given one in the opposite hemisphere, reversing the seasons: thus, if the length of *day* is required upon the 50th southern parallel, find the length of *night* upon the 50th northern one, and *vice versa.* The times of sunrise and sunset can be obtained from these lengths, according to direction 4 of First Method.

Note. — If the length of a number of successive days be obtained at places differing in latitude, this length will be found to change at a constantly increasing rate as we go towards the poles: thus 20° of the 20th parallel, and 70° of the 50th, pass into day in the same interval of 3 months. Again: day increases from 0 to 12 hours in 1 month and 20 days upon the 70th parallel, and in 18 days upon the 80th. This difference in the rate at which day changes in length upon different parallels is due to the varying diameters of the parallels: the smaller the diameter, the faster the rate at which the parallel crosses the day-circle: thus one-half of the parallel of 80° N. latitude crosses this circle while one-fourth of the parallel of 70° N. latitude is crossing it.

(*a*) The times of sunrise and sunset, length of day, &c., as found upon a globe, vary somewhat from astronomical exactness. This is because certain causes, which give rise to a variable rate of change of the sun's right ascension, are not allowed for upon a globe. For an explanation of these causes, see some treatise on astronomy.

PROBLEM XVIII.

To find the Length of a Period of Continuous Day upon a given Parallel in the North Frigid Zone; also when this Period begins and ends.

1. Bring June 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its farthest point from the solar index beneath the day-circle, and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its farthest point from the solar index again beneath the day-circle, and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates for the length of the given period. (*a*)

Exercises. — Find the beginning, end, and duration of a period of continuous day upon the parallel of 80° N. latitude.

Ans. — Length of period, four months: it begins April 21, and ends August 21.

Find the beginning, end, and duration of a period of continuous day upon the parallels of 70°, 75°, and 80° N. latitude.

(*a*) Problems are given upon *parallels* in the frigid zones, instead of *places*, because the latter are so few. As the earth rotates upon its axis, a place follows the direction of its parallel as regards the sun. Therefore, so long as either a part or the whole of the parallel is in day or night, a place upon it has a day or night which is either a part or the whole of 24 hours.

PROBLEM XIX.

To find the Length of a Period of Continuous Night upon a given Parallel in the North Frigid Zone; also when this Period begins and ends.

1. Bring December 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its nearest point to the solar index, beneath the day-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its nearest point to the solar index again beneath the day-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of continuous night upon the parallel of 70° N. latitude.

Ans. — Length of period, two months and twelve days: it begins November 15, and ends January 27.

Find the beginning, end, and duration of a period of continuous night upon the parallels of 75°, 80°, and 85° N. latitude.

PROBLEM XX.

To find the Length of a Period of Alternate Day and Night, succeeding one of Continuous Day, upon a given Parallel in the North Frigid Zone; also when this Period begins and ends.

1. Bring September 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its farthest point from the solar index beneath

the day-circle, and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its nearest point to the solar index beneath the day-circle, and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months upon the calendar disk the distance between the two dates for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of alternate day and night, succeeding one of continuous day, upon the parallel of 80° N. latitude.

Ans. Length of period, two months: it begins August 21, and ends October 21.

Find the beginning, end, and duration of a period of alternate day and night, succeeding one of continuous day, upon the parallels of 70°, 75°, and 85° N. latitude.

PROBLEM XXI.

To find the Length of a Period of Alternate Day and Night, succeeding one of Continuous Night, upon a given Parallel in the North Frigid Zone; also when this Period begins and ends.

1. Bring March 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its nearest point to the solar index beneath the day-circle, and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its farthest point from the solar index beneath the day-circle, and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months upon the calendar disk

the distance between the two dates for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of alternate day and night, succeeding one of continuous night, upon the parallel of 80° N. latitude.

Ans. — Length of period, two months: it begins February 21, and ends April 21.

Find the beginning, end, and duration of a period of alternate day and night, succeeding one of continuous night, upon the parallels of 70°, 75°, and 85° N. latitude.

N. B. — Problems upon the south frigid zone are worked upon the north frigid, reversing the seasons of day and night, thus: —

1. Given a period of continuous *day* in the south frigid zone, solve the problem for a period of continuous *night* in the north frigid.

2. Given a period of continuous *night* in the south frigid zone, solve the problem for a period of continuous *day* in the north frigid.

3. Given a period of alternate day and night, succeeding one of continuous *day*, in the south frigid zone, solve the problem for a period of alternate day and night, succeeding one of continuous *night*, in the north frigid.

4. Given a period of alternate day and night, succeeding one of continuous *night*, in the south frigid zone, solve the problem for a period of alternate day and night, succeeding one of continuous *day*, in the north frigid.

Note. — Two equal periods of alternate day and night, and two other equal periods, — namely, one of continuous day and one of continuous night, — compose the year in the frigid zones: therefore the length of a period of alternate day and night subtracted from 12 months, and divided by 2, will give the length of a period of continuous day or of continuous night, and *vice versa.* The length of these four periods is determined by the distance of the given parallel from the pole. Thus the two parallels of 70° and 80° north latitude have each a period of continuous day or of continuous night while the interval between the parallel and the polar circle is carried twice across the day-circle, or while the respective arcs of 5° and 25° cross this circle. Again: the same parallels have each a period of alternate day and night while the diameter of the parallel crosses the day-circle, or while the respective arcs of 40° and 20° cross this circle.

PROBLEM XXII.

At a given Place, the Day being given, to find what other Day of the Year is of the same Length.

FIRST METHOD.

1. Bring the given day to the calendar index.
2. Note the degree of latitude opposite the solar index.
3. Turn the calendar disk forward until the same degree is again brought opposite the solar index.
4. Look for the required day opposite the calendar index. (*a*)

SECOND METHOD.

Find how many days the given day is before the nearer solstice; and the required day is the same number after it, and *vice versa*.

THIRD METHOD.

Find how many days the given day is before the nearer equinox; and the required day is the same number after the subsequent one, and *vice versa*.

Exercises. — What day of the year is of the same length as April 15?

Ans. — August 27.

What day of the year is of the same length as March 4, May 15, August 30, October 12, December 21, June 2?

PROBLEM XXIII.

To find at what Latitude, not within the Polar Circles, a given Day is of a given Length.

FIRST METHOD.

1. Bring the given day to the calendar index.
2. Bring any meridian to the solar index. (*b*)

(*a*) The degree of latitude opposite the solar index shows the sun's declination. This is discussed in a problem farther on.

(*b*) The broad meridian passing through XII. in the hour-circle is the best one for this purpose.

3. Count from this meridian upon the equator, either to the east or the west, as many intervals of longitude as are equal to half the hours of the given day.

4. The same meridian being opposite the solar index as at first, follow along the meridian reached by counting, either towards the north or the south, according as the given latitude is north or south of the equator, until this meridian intersects the day-circle, where will be found the required latitude.

SECOND METHOD.

1. Bring the given day to the calendar index.

2. Bring the meridian of Greenwich to the solar index.

3. Set the hour-index to XII.

4. Turn the globe on its axis towards the east until the index has passed over as many hours as are equal to half the length of the given day.

5. Keep the globe from revolving on its axis, and follow along the meridian of Greenwich from XII. upon the hour-circle until this meridian intersects the day-circle, where will be found the required latitude.

Note. — When the required latitude is south of the equator, it may be found upon the north by substituting the length of the *night* of the given date for that of the day. Thus, if the latter is 16 hours, solve the problem for a day of 8 hours, and call the northern latitude, which is found, a southern one. It is sometimes more convenient to practise this method upon southern parallels.

Exercises. — In what degree of N. latitude is the length of the longest day 16 hours?

Ans. — In latitude 49°.

In what degree of *north* latitude is day, upon the 20th of May, 16 hours long? night upon the 1st of December, 13 hours long? In what degree of south latitude is the shortest day 8 hours long? In what degree of north latitude does the sun set at 7 o'clock on the 10th of April? In what degree of north latitude is the longest day five times the length of the night?

PROBLEM XXIV.

At a given Place, the Day and Hour being given, to find how the various Regions of the Earth are situated with regard to Day, Night, Twilight, &c.

1. Bring the given day to the calendar index.

2. Bring the given place into the given hour by Problem X.

All regions upon the day-side of the globe are now in day; all upon the night-side are in night.

It is noon upon the semi-meridian which bisects the day-side of the globe, or which is opposite the solar index.

It is midnight upon the semi-meridian which bisects the night-side of the globe.

The sun is vertical at the position opposite the solar index.

It is sunrise at places beneath the day-circle, upon the left of the semi-meridian which is in noon.

It is sunset at places beneath the day-circle, upon the right of the semi-meridian which is in noon.

It is the beginning of morning twilight at places beneath the twilight-circle, upon the west of the semi-meridian which is in noon; those parallels being excepted which lie wholly upon the night-side of the globe.

It is the end of evening twilight at places beneath the twilight-circle, upon the east of the semi-meridian which is in noon; those parallels being excepted which lie wholly upon the night-side of the globe.

It is continuous day at places whose parallels lie wholly upon the day-side of the globe.

It is continuous night at places whose parallels lie wholly upon the night-side of the globe.

It is continuous twilight at places whose parallels lie wholly within the section of twilight.

It is continual dark-night, or a night without any twilight, at places whose parallels lie upon the night-side of the globe, beyond the section of twilight.

Twilight and dark-night alternate, during every 24 hours, at places whose parallels are divided by the twilight-circle, and which do not extend upon the day-side of the globe.

Twilight continues from sunset to sunrise at places whose parallels, being divided by the day-circle, have their unilluminated arcs wholly within the section of twilight.

Exercises. — When it is 4 h. 52 m. A.M. at London on March 5, where is the sun rising, setting, &c., &c.?

Ans. — The sun is rising at Riga, the western part of Greece, &c.; setting at the Gulf of Anadir, Fox Islands, &c.; it is noon at Lake Baikal, Gulf of Tonquin, &c.; midnight at New York, Montreal, &c.; morning twilight at Norway, Sweden, &c.; evening twilight at Alaska, the Sandwich Islands, &c.; day at China, Australia, &c.; night at the United States, Mexico, &c.; the sun is vertical at Batavia.

Where is the sun rising, setting, &c., &c., when it is 2 P.M. at Washington, October 10? noon at Quebec, May 1? 11 A.M. at Dublin, September 1? 4 P.M. at Rome, November 4? 6 h. 30 m. A.M. at Constantinople, December 10? 11 h. 15 m. A.M. at Cairo, April 16?

PROBLEMS UPON THE SUN.

PROBLEM XXV.

To pass the Globe through the four Seasons of Spring, Summer, Autumn, and Winter; also to show how the Northern and the Southern Hemispheres are illuminated upon a given Day, and the Sun's Place in the Ecliptic.

1. Pass the globe through a northern spring and southern autumn by turning the calendar disk forward three months from March 21.

2. Pass the globe through a northern summer and southern winter by turning the calendar disk forward three months from June 21.

3. Pass the globe through a northern autumn and southern spring by turning the calendar disk forward three months from September 21.

4. Pass the globe through a northern winter and southern summer by turning the calendar disk forward three months from December 21.

5. Show how the northern and the southern hemispheres are illuminated at any given time by bringing this time to the calendar index, and noting the most northern and southern positions of the day-circle; also the position at which the sun is vertical.

6. Look for the sign and degree opposite the given day for the sun's place in the ecliptic.

N. B. — The globe being set in position for a given time, — say August 24, — what this time is designed to show in this problem may be stated as follows: namely, upon August 24 the sun shines from the point in the 80th northern parallel the farthest from it to the point in the 80th southern parallel the nearest to it; it is vertical at the 10th northern parallel, and is in the 3d° of the sign Virgo of the ecliptic.

Exercises. — Pass the globe through a northern winter, a southern autumn, a southern spring, a northern spring, a northern summer, a southern winter.

Show and state how the northern and the southern hemispheres are illuminated; also the sun's place in the ecliptic upon July 10, September 1, November 18, December 21, March 21, June 1.

PROBLEM XXVI.

To show the Rate at which the Sun moves between the Tropics; a Rate bearing a close Relation to the Rate at which Day or Night changes in Length, or the Rate at which the Sun's Diurnal Arcs increase or decrease in Extent.

Turn the calendar disk either from June 21 to December 21, or from December 21 to June 21, and observe the rate at which the solar index moves towards the north or the south upon the globe, estimating this rate in degrees at the close of each month.

Note.—As an example of the unequal rate at which day increases or decreases from month to month, contrast the following figures, showing the increase of day at Boston from December 21 to June 21: viz., 29 m. from December 21 to January 21; 73 m. from January 21 to February 21; 83 m. from February 21 to March 21; 86 m. from March 21 to April 21; 71 m. from April 21 to May 21; and 30 m. from May 21 to June 21.

PROBLEM XXVII.

The Day being given, to find the Sun's Longitude, Right Ascension, and Declination.

1. Find the sun's place in the ecliptic according to direction 6, Problem XXV.: the distance of this place from the first degree of Aries, reckoning towards the right, is the sun's longitude.

2. Mark where this longitude occurs upon the circle of the ecliptic, as drawn upon the globe; that is, pass to a point as many degrees east of the first point of Aries as equal the sun's longitude. Follow from this point to the equator along a meridian, and the distance from this second point to the first degree of Aries is the sun's right ascension.

3. Bring the given day to the calendar index, and the

degree of latitude opposite the solar index is the sun's declination.

Exercises. — Find the longitude, right ascension, and declination of the sun on May 10.

Ans. — Longitude, 49°; right ascension, 47°; declination, 8°.

Find the longitude, right ascension, and declination of the sun on July 4, November 6, April 21, June 1, August 10, February 18.

PROBLEM XXVIII.

The Day being given, to find those Places where the Sun is Vertical, or in the Zenith, at Noon.

1. Find the sun's declination for the given day according to direction 3, Problem XXVII.

2. Turn the globe on its axis, and all places passing opposite the solar index have the sun vertical at noon.

Exercises. — Find those places where the sun is vertical at noon upon April 20.

Ans. — It is vertical at places upon the tenth northern parallel; viz., at Cochin, Gulf of Siam, Gulf of Darien, Trinidad Island, &c.

Find those places where the sun is vertical at noon upon July 4, June 21, September 1, November 15, January 8, March 1.

PROBLEM XXIX.

The Day, Hour, and Place being given, to find where the Sun is Vertical.

1. Bring the given day to the calendar index.

2. Bring the given place into the given hour by Problem X.

3. Look for the required place opposite the solar index.

Exercises. — When it is 11 P.M. at New York on the 1st of May, where is the sun vertical?

Ans. — At Manilla.

Where is the sun vertical when it is 2 h. 20 m. P.M. at Madras on the 27th of February? 8 h. 36 m. A.M. at London on March 28? 2 h. 15 m. P.M. at Calcutta on April 24? 11 P.M. at Cape Sable, Florida, on June 21? 7 h. 40 m. A.M. at Cape Verde on August 12? 9 A.M. at Charleston on October 7?

PROBLEM XXX.

To find those two Days of the Year on which the Sun will be Vertical at a given Place in the Torrid Zone.

1. Turn the calendar disk to bring the latitude of the given place opposite the solar index.
2. Note the date opposite the calendar index for one of the days.
3. Turn the calendar disk forward until the latitude of the given place is again opposite the solar index.
4. Note the date opposite the calendar index for the other day.

Exercises. — On what two days of the year is the sun vertical at Batavia, in the Island of Java?

Ans. — On the 4th of March and the 8th of October.

On what two days of the year is the sun vertical at Manilla? Lima? Gondar? Singapore? Cape St. Roque? Aden?

PROBLEM XXXI.

The Length of the Day at any Place being given, to find the Sun's Declination, and the two Days of the Year on which it has this Declination.

FIRST METHOD.

1. Bring the meridian of the given place to the solar index.

2. Turn the globe on its axis, either towards the west or the east, until the solar index has passed over as many intervals of longitude as are equal to half the hours of the given day.

3. Keep the meridian which is now opposite the solar index in this position, and turn the calendar disk either forward or backward until the given place is beneath the day-circle.

4. Look for one of the required days opposite the calendar index.

5. Find the other required day by Problem XXII.; or turn the calendar disk forward (still keeping opposite the solar index the meridian brought to it by turning the globe on its axis the required amount) until the given place is again beneath the day-circle, when the day sought will again be found opposite the calendar index.

6. Find the sun's declination, upon both days, at the degree of latitude opposite the solar index, according to direction 3, Problem XXVII.

SECOND METHOD.

1. Bring the meridian of the given place to the solar index.

2. Set the hour-index to XII.

3. Turn the globe on its axis towards the east until the hour-index has passed over half the hours of the given day.

4. Keeping the meridian which is now opposite the solar index in this position, turn the calendar disk either forward or backward until the given place is beneath the day-circle.

5. Look for one of the required days opposite the calendar index.

6. Find the other required day by Problem XXII.; or turn the calendar disk forward (still keeping opposite the solar index the meridian brought to it by turning the globe on its axis the required amount) until the given place is

again beneath the day-circle, when the day sought will again be found opposite the calendar index.

7. Find the sun's declination, upon both days, at the degree of latitude opposite the solar index, according to direction 3, Problem XXVII.

Exercises. — What two days of the year are each 14 hours long at New York? and what is the sun's declination on these two days?

Ans. — The 6th of May and the 6th of August; sun's declination, 17° N.

What two days of the year are each 10 hours long at Boston? 6 hours long at Dublin? 13 hours long at Rome? What two nights of the year are each 7 hours long at Cape Race? 18 hours long at Sitka? What two days of the year are each 14 hours long at Sydney, Australia? Give the sun's declination in each case.

N. B. — This last problem upon Sydney can be more conveniently solved upon the corresponding place in the northern hemisphere, or latitude 35° N., longitude same as that of Sydney. If this is done, the length of the *night* of the required dates, or the difference between the given length and 24 hours, must be substituted for the given length, — a course already indicated in a preceding problem. (See Problem XXIII., Second Method, note.)

PROBLEM XXXII.

A Place and the Day of the Year being given, to find how much the Sun's Declination must vary to make the Day a given Time longer or shorter than the given Day; also how many Days will elapse during the change.

FIRST METHOD.

1. Bring the given day to the calendar index.
2. Note the sun's declination.
3. Bring the meridian of the given place to the solar index.

4. Note, upon the parallel of the given place, the longitude beneath the day-circle, either upon the east or the west.

5. Reduce one-half of the given increase or decrease of time to degrees of longitude by Problem XII., First Method.

6. Keep the meridian of the given place opposite the solar index, and turn the calendar disk forward until the number of degrees of longitude obtained have passed either into day or night, according as the day is to be made longer or shorter at the given place.

7. Note the sun's declination, and its distance in degrees from the declination found upon the given day will be the required change: the distance of the calendar index from the given day will give the required number of days.

SECOND METHOD.

1. Bring the given day to the calendar index.

2. Note the sun's declination.

3. Bring the meridian of the given place to the solar index.

4. Set the index to XII.

5. Turn the globe on its axis towards the east until the given place is beneath the day-circle.

6. Note the time to which the hour-index points.

7. If the day is to be made longer, continue to turn the globe towards the east until the hour-index has passed over a time equal to one-half of the given increase of time.

8. If the day is to be made shorter, turn the globe towards the west until the hour-index has passed over a time equal to one-half of the given decrease of time.

9. Turn the calendar disk forward (keeping opposite the solar index the meridian brought to it by turning the globe on its axis the required amount) until the given place is brought beneath the day-circle.

10. Note the sun's declination, and its distance from the declination found upon the given day will be the required change: the distance of the calendar index from the given day will give the required number of days.

Exercises. — How much must the sun's declination vary, in order that day at London may be one hour longer than on the 29th of February? also how many days will elapse during the change?

Ans. On the 29th of February, the sun's declination is about 9° S.; and the 82d degree of E. longitude, upon the parallel of London (the meridian of London being opposite the solar index), is beneath the day-circle upon the east. To increase the day an hour, 7½° must be added to the number, or the 89th degree of E. longitude brought to the day-circle. Turning the calendar disk forward till this increase is made, the meridian of London being constantly held opposite the solar index, the sun is now vertical at the fourth southern parallel, and the calendar index is opposite March 15: hence the sun's declination has decreased about 5°, and fifteen days have elapsed, while day at London is 1 hour longer than on February 29.

How much must the sun's declination vary, that day at Boston may be 1 hour shorter than on the 30th of June? that night at Copenhagen may be 1 hour longer than on January 1? that day at Canton may be 30 minutes longer than on April 1? that day at Dublin may be 2 hours longer than on May 1? that day at Stockholm may be 3 hours shorter than on June 21? that day at Sydney, Australia, may be 1 hour longer than on July 1? State in each case how many days will elapse during the change.

N. B. — The problem upon Sydney, Australia, can be solved upon the parallel of 35° *north* latitude, instead of south, if more convenient; but, if this is done, day must *decrease* instead of increase.

PROBLEM XXXIII.

To find in what Latitude the Sun does not set during a given Number of Days in the Frigid Zone.

1. If the required latitude is north, bring June 21 to the calendar index; if south, December 21.

2. Turn the calendar disk forward one-half the given number of days.

3. If the required latitude is north, find it at the northern parallel whose farthest point from the solar index is beneath the day-circle.

4. If the required latitude is south, find it at the *northern* parallel whose *nearest* point to the solar index is beneath the day-circle, this parallel being upon the night-side of the globe.

Exercises.—In what degree of north latitude, and at what places, does the sun continue above the horizon for 78 days?

Ans. The 72d degree, or at Cape North, in Lapland, the southern part of Nova Zembla, Point Beechy, &c. In what degree of north latitude, and at what places, does the sun continue above the horizon for 2 months? 4 months? 20 days? In what degree of south latitude does the sun continue above the horizon for 3 months? 5 months? 50 days?

PROBLEM XXXIV.

Given a Day, to find the Equation of Time, or the Difference between Sun-Time and Clock-Time.

1. Find the sun's longitude and right ascension for the given day by Problem XXVIII.

2. Subtract the smaller from the greater, and reduce the difference to minutes by multiplying by four. If the lon-

gitude is the smaller, the sun is slower than the clock; if the right ascension is the smaller, the clock is slower than the sun.

Exercises. — What is the difference between sun-time and clock-time on the 17th of July?

Ans. — The sun's right ascension exceeds its longitude by two degrees: hence the sun is eight minutes slower than the clock.

What is the equation of time on August 10? June 21? March 1? September 21? November 4? April 10?

PROBLEM XXXV.

To describe the Course of the Sun, with respect to the Horizon and Visible Heavens, at a given Place upon a given Day.

N. B. — Remove the brass circles, and place the ring arrangement upon the globe. Have the *un*-notched extremity of the brass meridian towards you.

1. Bring the given day to the calendar index.

2. Adjust the ring arrangement to the given place. (*a*)

3. Turn the globe on its axis to bring the brass horizon to the solar index, with the brass meridian upon the west of it.

4. Note the degree upon the brass horizon which is opposite the solar index for the sun's rising amplitude. If the solar index is opposite the equator, the sun is rising in the east; if the solar index is north or south of the equator, the sun is rising north or south of east.

5. Turn the globe on its axis towards the east until the brass meridian is brought opposite the solar index.

6. Note the degree upon the brass meridian which is opposite the solar index for the sun's meridian altitude. Subtract this altitude from 90° for the sun's zenith dis-

(*a*) See manner of doing this in "Description of Globe," p. 55.

tance, or read this distance between the solar index and the perforation which is at the given place.

7. Continue to turn the globe towards the east until the brass horizon is again brought opposite the solar index.

8. Note the degree upon the brass horizon which is opposite the solar index for the sun's setting amplitude. If the solar index is opposite the equator, the sun is setting in the west; if the solar index is north or south of the equator, the sun is setting north or south of west.

9. Continue to turn the globe towards the east until the solar index is a third time brought to the brass horizon, thus describing the night-arc of the given parallel.

10. Continue to turn the globe towards the east while the required course of the sun is again described, and contrast the length of the day-arc with that of the night-arc; this contrast showing that of day and night, in regard to length, at the given place upon the given day.

N. B. — Whenever the sun's course is to be described at a place in the southern hemisphere, adjust the ring arrangement to the antipodes of the place (see Problem VI.), and ascertain the sun's meridian altitude and zenith distance upon the meridian passing through the place, the brass meridian being now below the horizon. The meridian altitude is the number of degrees between the solar index and the nearer extremity of the brass meridian, and the zenith distance is the number between the solar index and the given place. When the solar index is opposite the perforation (in the northern hemisphere) or the given place (in the southern), the sun is represented in the zenith.

When adjusting the ring arrangement to a place upon the equator, set the *notched* extremity of the brass meridian around the south pole.

Exercises. — Describe the course of the sun at London upon December 21.

Ans. — Upon December 21, at London, the sun rises 42° S. of E., attains a meridian altitude of 14°, and sets 42° S. of W.

Describe the sun's course at Spitzbergen upon March

21; at Quito upon May 1; at Magadoxa upon November 10; at Para upon November 1; at Tonquin upon August 1; at Rome upon July 5; at Madrid upon April 15; at Quebec upon October 7; at Cape Prince of Wales upon December 21; at Sydney, Australia, upon June 21; at Spitzbergen upon April 21; at Hammerfest, Qualoe Islands, upon April 1; at the North Pole upon July 30; at the South Pole upon January 5.

PROBLEM XXXVI.

To find the Sun's Altitude and Azimuth at a given Place, the Day and Hour being known.

1. Bring the given day to the calendar index.
2. Adjust the ring arrangement to the given place.
3. Bring the given place into the given hour by Problem X.
4. Attach the altitude quadrant to the perforation in the brass meridian, and extend it to the brass horizon in the direction of the solar index: the number of degrees between this index and the brass horizon is the required altitude; the number of degrees intercepted on the brass horizon from the north or the south point is the required azimuth.

Exercises. — What are the sun's altitude and azimuth at London on the 1st of May at 10 A.M.?

Ans. — Altitude, 47°; azimuth, 136° from the N. point.

Find the altitude and azimuth of the sun at New York, November 5, 2 P.M.; Berlin, June 10, 8 A.M.; Rome, May 1, 4 P.M.; Boston, December 21, 1 P.M., 3 P.M.; Spitzbergen, July 21, 1 A.M., 4 P.M., 10 P.M.

PROBLEM XXXVII.

To find the Region of the Earth in which a Solar Eclipse is visible, the Time of its Occurrence at Washington being given.

1. Find the place where the sun is vertical at the beginning of the eclipse by Problem XXIX.: at all places within 35° of this place, the beginning of the eclipse is visible.

2. Repeat the process for the time of the end of the eclipse, obtaining a region where the end of the eclipse is visible. At those places which are common to both regions, thus found, the whole eclipse is visible.

N. B. — The region of the eclipse may be defined upon the globe by moving the quadrant around the place illuminated by a vertical sun, and observing the circle swept at a distance of 35°.

Exercises. — On June 5, 1872, there was an annular eclipse of the sun; beginning at 7 h. 12 m., and ending at 13 h. 10 m., Washington time. Where was this eclipse visible?

On March 25, 1876, there was an annular eclipse of the sun; beginning at 0 h. 21 m., and ending at 5 h. 32 m., Washington time. Where was this eclipse visible?

PROBLEM XXXVIII.

To find the Region of the Earth in which a Lunar Eclipse is visible, the Time of its Occurrence at Washington being given.

1. Find the place where the sun is vertical at the beginning of the eclipse by Problem XXIX. At all places upon the night-side of the globe, the beginning of the eclipse is visible.

2. Repeat the process for the end of the eclipse, obtaining a hemisphere where the end of the eclipse is visible.

At those regions which are common to both hemispheres, thus found, the whole eclipse is visible.

Exercises.—On May 22, 1872, there was a partial eclipse of the moon; beginning at 5 h. 32 m., and ending at 6 h. 48 m., Washington time. Determine whether the beginning and end of this eclipse were visible at Dublin.

On March 9, 1876, there was a partial eclipse of the moon; beginning at 12 h. 13 m., and ending at 14 h. 13 m., Washington time. Where was this eclipse visible?

Note.—A solar eclipse is a partial or total obscuration of the sun, caused by the interposition of the moon between the earth and the sun.

A lunar eclipse is a partial or total obscuration of the moon, caused by the interposition of the earth between the moon and the sun.

PROBLEMS UPON TWILIGHT.

PROBLEM XXXIX.

A Place and Day of the Year being given, to find the Length of Morning and Evening Twilight.

Note.—A place having morning and evening twilight must be situated upon a parallel that extends upon both sides of the section of twilight. Morning twilight is upon the west, and evening twilight upon the east. The two arcs which measure these periods upon a given parallel are seen to contain the same number of degrees, since they proceed through the section of twilight in the same direction. Parallels within 48½° of the equator always have morning and evening twilight.

FIRST METHOD.

1. Bring the given day to the calendar index.
2. Look for the parallel upon which the given place is

situated, and count the intervals of longitude upon this parallel which are within the section of twilight, either upon the east or the west. The number of these intervals is the number of hours in the required length. (*a*)

SECOND METHOD.

1. Bring the given day to the calendar index.

2. Set the hour-index to XII.

3. Bring the given place either to the twilight-circle upon the west, or to the day-circle upon the east.

4. Turn the globe on its axis towards the east until the given place is carried through the section of twilight. The hour-index will now point to the required length.

Exercises. — Find the length of morning and evening twilight at London on the 23d of September.

Ans. — Two hours.

Find the length of morning and evening twilight at Boston, June 21; Havana, October 10; Santiago, February 5; Dublin, August 20; Madrid, November 1; Pekin, December 10.

PROBLEM XL.

A Place and Day of the Year being given, to find when Morning Twilight begins, and Evening Twilight ends.

FIRST METHOD.

1. Bring the given day to the calendar index.

2. Bring the meridian of the given place to the solar index.

3. Count the intervals of longitude which lie between this meridian and the twilight-circle upon the west, reck-

---

(*a*) These intervals can be more readily counted upon a parallel by bringing the oceanic surface of the globe within the section of twilight.

oning upon the parallel of the given place. The number obtained, being subtracted from 12, will give the hour when morning twilight begins.

4. Count in the same manner towards the east. The number obtained will give the hour when evening twilight ends; or the number obtained when counting towards the west will also give it.

SECOND METHOD.

Find the times of sunrise and sunset by Problem XVII., and the length of twilight by Problem XL. This length, subtracted from the time of sunrise, will give the beginning of morning twilight; and the same length added to the time of sunset will give the end of evening twilight.

THIRD METHOD.

1. Bring the given day to the calendar index.

2. Bring the meridian of the given place to the solar index.

3. Set the hour-index to XII.

4. Turn the globe on its axis towards the west until the given place is brought to the twilight-circle. The hour-index will now point out the beginning of morning twilight.

5. Turn the globe on its axis towards the east until the given place is brought to the twilight-circle in this direction. The hour-index will now point out the end of evening twilight.

Exercises. — Find when morning twilight begins and evening twilight ends at London on the 19th of April.

Ans. — Morning twilight begins at 2 h. 40 m., and evening twilight ends at 9 h. 20 m.

Find when morning twilight begins and evening twilight ends at Washington, April 10; Cincinnati, November 4; Cape St. Lucas, January 15; Jeddo, August 1; Manilla, October 21; Valparaiso, June 5.

N. B. — Whenever it is not convenient to find the length of morning and evening twilight upon a southern parallel, find this length upon the corresponding northern parallel for a date six months forward. Thus, if the given day at the southern parallel is August 5, bring February 5 to the calendar index. (*a*)

PROBLEM XLI.

To find the Length of a Period of Twilight lasting from Sunset to Sunrise at a given Place in the Temperate Zone; also when this Period begins and ends.

Note. — This period occurs once a year at latitudes higher than 48½°. It attains the middle of its duration on June 21.

1. Bring June 21 to the calendar index.

2. Turn the calendar disk backward until the parallel upon which the given place is situated has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the parallel upon which the given place is situated again has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of twilight lasting from sunset to sunrise at Stockholm.

(*a*) The sun moves below the horizon of a place at the same time and rate that the place moves beyond the day-circle into night; and hence it is that twilight is as correctly measured from the day-circle, along the parallel of the given place, as from the horizon, along the circle of declination which the sun is describing.

Ans. — Length of period, 3 months, 28 days: it begins April 22, and ends August 20.

Find the beginning, end, and duration of a period of twilight lasting from sunset to sunrise, at Dublin, London, St. Petersburg, Tobolsk, Okolsk, Nain (Labrador).

PROBLEM XLII.

To find the Length of a Period of Twilight lasting from Sunset to Sunrise upon a given Parallel of the Frigid Zones; also when this Period begins and ends.

Note. — This period occurs twice a year at places within the frigid zones.

FIRST METHOD. — *The given period succeeding one of continuous day.*

1. Bring June 21 to the calendar index.

2. Turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the day-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Continue to turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

SECOND METHOD. — *The given period succeeding one of continuous night.*

1. Bring December 21 to the calendar index.

2. Turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the

twilight-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Continue to turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the day-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of twilight lasting from sunset to sunrise, and succeeding one of continuous day, upon the parallel of 80° N. latitude.

Ans. — Length of period, 1 month, 18 days: it begins August 24, and ends October 14.

Find the beginning, end, and duration of a period of twilight lasting from sunset to sunrise, and succeeding one of continuous day, upon the parallels of 70° and 85° N. latitude, upon the Arctic Circle.

Find the beginning, end, and duration of a period of twilight lasting from sunset to sunrise, and succeeding one of continuous night, upon the parallels of 70° and 75° N. latitude; upon the parallel of 85° S. latitude.

N. B. — Whenever the length of a period of twilight upon a southern parallel is required (except when twilight occurs as morning and evening), obtain this length upon the corresponding parallel in the north frigid zone, and carry the dates found six months forward. Thus, if a period of twilight lasts from sunset to sunrise from August 21 to October 11 upon the 80th northern parallel, it lasts from February 21 to April 11 upon the 80th southern parallel.

PROBLEM XLIII.

To find the Length of a Period of Continuous Twilight upon a given Parallel in the Frigid Zones; also when this Period begins and ends.

Note. — This period occurs twice in the year upon parallels within 9° of the poles.

FIRST METHOD. — *The given period beginning a period of continuous night.*

1. Bring December 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its nearest point to the solar index, beneath the day-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the date of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

SECOND METHOD. — *The given period ending a period of continuous night.*

1. Bring December 21 to the calendar index.

2. Turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Continue to turn the calendar disk forward until the given parallel has its nearest point to the solar index, beneath the day-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk,

the distance between the two dates, for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of continuous twilight upon the parallel of 85° N. latitude; this period beginning one of continuous night.

Ans. — Length of period, 22 days: it begins October 6, and ends October 28.

Find the beginning, end, and duration of a period of continuous twilight upon the parallels of 82° and 88° N. latitude; this period beginning one of continuous night.

Find the beginning, end, and duration of a period of continuous twilight upon the parallel of 82° N. latitude; at the South Pole, this period ending one of continuous night.

PROBLEM XLIV.

To find the Length of a Period of Twilight alternating every twenty-four hours with Dark-Night upon a given Parallel in the Frigid Zones; also when this Period begins and ends.

Note. — This period occurs twice in the year upon parallels within 5° of the poles, and once in the year upon larger parallels.

FIRST METHOD. — *The given parallel being at a distance of of more than 9° from the poles, and the given period attending the entire period of continuous night.*

1. Bring December 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its nearest point to the solar index, beneath the day-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its nearest point to the solar index, again beneath the day-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

SECOND METHOD. — *The given parallel being distant from the poles less than 9° and more than 5°, and the given period occurring between the periods of continuous twilight.*

1. Bring December 21 to the calendar index.
2. Turn the calendar disk backward until the given parallel has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the beginning of the given period.
3. Turn the calendar disk forward until the given parallel has its farthest point from the solar index, again beneath the twilight-circle; and note the date opposite the calendar index for the end of the given period.
4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

THIRD METHOD. — *The given parallel being within 5° of the poles, and the given period preceding one of continuous twilight.*

1. Bring December 21 to the calendar index.
2. Turn the calendar disk forward until the given parallel has its nearest point to the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the beginning of the given period.
3. Continue to turn the calendar disk forward until the given parallel has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the end of the given period.
4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

FOURTH METHOD.— *The given parallel being within 5° of the poles, and the given period following one of continuous twilight.*

1. Bring December 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its farthest point from the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its nearest point to the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

Exercises. — Find the beginning, end, and duration of a period of twilight alternating every 24 hours with dark-night upon the parallel of 75° N. latitude.

Ans. — Length of period, 3 months, 15 days: it begins October 30, and ends February 15.

Find, according to First Method, the length of a period of twilight alternating every 24 hours with dark-night upon the parallels of 70° and 77° N. latitude.

Find, according to Second Method, the beginning, end, and duration of a period of twilight alternating every 24 hours with dark-night upon the parallels of 82° and 84° N. latitude.

Find, according to Third Method, the beginning, end, and duration of a period of twilight alternating every 24 hours with dark-night upon the parallels of 86° and 88° N. latitude.

Find, according to Fourth Method, the beginning, end, and duration of a period of twilight alternating every 24 hours with dark-night upon the parallels of 86° and 88° N. latitude.

PROBLEM XLV.

To find the Length of a Period of Dark-Night upon a given Parallel in the Frigid Zones; also when this Period begins and ends.

Note.—This period occurs once a year upon parallels within 5° of the poles.

1. Bring December 21 to the calendar index.

2. Turn the calendar disk backward until the given parallel has its nearest point to the solar index, beneath the twilight-circle; and note the date opposite the calendar index for the beginning of the given period.

3. Turn the calendar disk forward until the given parallel has its nearest point to the solar index again beneath the twilight-circle, and note the date opposite the calendar index for the end of the given period.

4. Estimate in days or months, upon the calendar disk, the distance between the two dates, for the length of the given period.

Exercises.— Find the beginning, end, and duration of a period of dark-night upon the parallel of 88° N. latitude.

Ans.— Length of period, 1 month, 15 days: it begins November 27, and ends January 12.

Find the beginning, end, and duration of a period of dark-night upon the parallel of 86° N. latitude; at the North Pole; at the South Pole.

N. B.—Whenever the length of a period of dark-night upon a southern parallel is required, obtain this length upon the corresponding northern parallel, and carry the dates found six months forward, as was stated concerning twilight at the close of Problem XLII.

MISCELLANEOUS PROBLEMS.

1. FIND the difference of longitude between New York and San Francisco.

2. At what rate per hour are the inhabitants of Botany Bay carried from west to east by the rotation of the earth on its axis?

3. Bring Washington into 9 o'clock A.M.

4. Find the difference of time between Boston and Rome.

5. When it is 2 o'clock P.M. at Cincinnati, where is it 11 P.M.?

6. Find the times of sunrise and sunset, and the lengths of the day and the night, at Paris upon May 14.

7. What is the length of a period of continuous day at the northern extremity of Nova Zembla? and when does this period begin and end?

8. Find the beginning, end, and duration of a period of alternate day and night, succeeding one of continuous day, upon the parallel of 75° S. latitude.

9. In what degree of south latitude is the longest day 16 hours in length?

10. What two days of the year are each 17 hours long at Stockholm?

11. In what latitude north is the longest day eleven times the length of the shortest?

12. Find the longitude, right ascension, and declination of the sun on March 10.

13. Where is the sun vertical when it is 1 h. 40 m. P.M. at Edinburgh?

14. On what two days of the year is the sun vertical at Bombay?

15. How much must the sun's declination vary, that day at Liverpool may increase two hours from December 21? and how many days will elapse during the change?

16. In what degree of north latitude, and at what places, does the sun continue above the horizon for 40 days?

17. What is the equation of time on November 1?

18. Describe the course of the sun at Paris on June 10.

19. Find the altitude and azimuth of the sun at New York on March 1, 4 o'clock P.M.

20. Find the length of morning and evening twilight at Vienna on September 1.

21. On what day of the year is twilight eight hours long at London?

22. Find the beginning, end, and duration of a period of twilight, lasting from sunset to sunrise, at the Orkney Islands.

23. When the sun's meridian altitude at London is 30°, what day of the year is it?

24. On what day of the year is the sun's meridian altitude at Paris equal to the latitude of Paris?

25. What is the sun's altitude at Philadelphia on May 7, 3 o'clock P.M.?

26. What is the sun's greatest meridian altitude at the southern extremity of Patagonia?

27. In what latitude north does the sun begin to shine constantly on April 10?

28. If the meridian altitude of the sun on June 7 is 50°, what is the latitude of the place?

29. At what hour does the sun rise at London when it sets at 7 o'clock at St. Petersburg?

30. What place of the earth has the sun in the zenith when it is 7 o'clock A.M. at London on April 25?

31. Find, in the southern hemisphere, a city at which the meridian altitude of the sun on December 21 is 79° 30′, the sun being towards the northern point of the horizon, and the chronometer showing London time to be 1 h. 56 m. A.M. when it is noon in the city.

32. Find a city in which one has no shadow on the longest day of the year, and on every other day the shadow falls towards the north, and at which it is noon when it is 8 h. 12 m. A.M. at London.

33. Find a cape in the northern hemisphere at which, on the longest day in the year, the sun sets, and, without any intervening night, rises immediately in the same part of the horizon; and also where it is 12 h. 40 m. A.M. when it is noon at London.

QUESTIONS FOR EXAMINATION.

SECTION I.

1. DEFINE a point, line, straight line, curve, surface, plane curved surface.

2. Define a circle and its parts. Point out these parts in Fig. 1.

3. Define an angle. How are angles measured? How is the circumference of a circle divided? To what is the absolute length of a degree proportional? What may we take as the measure of an angle? Define a right angle; angular distances; a diedral angle. State the measure of the angles represented in Figs. 2 and 3.

4. Define a solid, a sphere and its parts. Define and illustrate great and small circles. Define and illustrate the poles of a great circle of a sphere.

5. What is said regarding angular motion? angular velocity?

SECTION II.

6. Describe the shape of the earth. What is its greatest circumference? its greatest diameter? its smallest diameter?

7. What is a terrestrial globe?

8. Define the axis of the earth, its poles, equator, meridians, parallels of latitude, the tropics, polar circles, zones.

9. What is said of latitude? what of longitude?

10. Prove that any two meridians include between them, whether measured upon the equator or a parallel, the same number of degrees.

11. What does Fig. 5 illustrate?

SECTION III.

12. Define the celestial sphere, poles, equator, celestial meridian of a place, parallels of declination, hour-circles.

13. Define the horizon. Distinguish between the rational and the sensible horizon. Define the zenith, nadir, vertical circles, the prime vertical, the cardinal points of the horizon.

14. Define altitude, meridian altitude, zenith distance, azimuth, amplitude, declination, right ascension, right sphere, parallel sphere, oblique sphere.

15. Define the ecliptic, and state its divisions. What are the cardinal signs of the ecliptic? What is said concerning the cardinal points of the ecliptic?

SECTION IV.

N. B.— The numbers following questions in this section indicate the article in which the answer is to be found. Answers continue to be found in the same article until a new number occurs.

16. What two motions of the heavenly bodies are apparent in the sky? **56.**

17. What question arises regarding these two motions? **57.**

18. Is it easy for an inhabitant of the earth to conceive it in motion? **58.** State cases in which it is difficult to distinguish between a state of motion and one of rest.

19. Granting that the movements of the heavenly bodies may belong either to themselves or to the earth, which is the more probable supposition? **59.**

20. Mention experiments furnishing proofs of the earth's rotation. **60.**

21. How may the annual movement of the heavenly bodies be made evident to the eye? **61.** What renders it probable that the earth has an annual motion around the sun?

22. In what common plane do the earth and sun at all times lie? **62.** What is the shape of the orbit of the earth within this plane? Show wherein an ellipse differs from a circle.

23. Does the ellipse of Fig. 9 represent correctly the ellipse described by the earth round the sun?

24. When is the earth said to be in perihelion? when in aphelion? What is its distance from the sun in these two positions?

25. What is the extent of the earth's orbit? the velocity of the earth in this orbit?

26. Describe the direction which the earth takes in its orbit. **63.** How does this direction compare with that of the sun in the ecliptic? Give the illustration.

27. How is the axis of the earth directed regarding the plane of its orbit? **64.**

28. How is it shown that the planes of the ecliptic and the equator are inclined to each other?

29. Give the illustration of the pencil, explaining the parallelism of the earth's axis. **65.**

30. Show why the earth's axis always appears to be directed towards the same points in the heavens.

31. What causes the alternation of day and night? **66.** Show why it is that the sun illuminates one-half of the earth's surface at all times. What is meant by the day-circle?

32. How may we illustrate the alternation of day and night?

33. When is there a day and a night of 12 hours each over the entire earth? **67.** Give facts showing the variations which these undergo in length in the course of the year.

34. What attendant changes take place in the diurnal course of the sun? **68.** To what common cause are these changes and those of the length of the day due?

35. What are shown in Fig. 12? **69.**

36. What is said of the positions marked vernal and autumnal equinox? Why are day and night always 12 hours in length at the equator?

37. Why are March 21 and September 21 called the equinoxes? Date the equinoxes in the southern hemisphere.

38. How far from the equator do the sun's rays extend upon 21 and September 21? Why are these two dates called the solstices? Date the solstices in the two hemispheres.

39. Astronomically considered, when do the four seasons of the year begin?

40. Follow out, with the aid of Fig. 12, the change of day and night between these several dates. **70.**

41. What movement of the northern and southern hemi-

spheres, regarding the sun, do these changes show to us? Illustrate this by reference to Fig. 11.

42. How does approach towards the pole affect the difference in the length of day and night?

43. Why are the tropics and polar circles distinguished from the other parallels upon the earth's surface? **71.**

44. When do parallels have a day and a night every twenty-four hours? **72.** When does their day or night continue longer than 24 hours? Why is it that the parallels of the frigid zones are subject to a greater variety of day and night, as regards length, than occurs within the temperate and torrid zones?

45. Name the four periods of day and night which these parallels may be said to have during the year.

46. State the middle of these four periods.

47. Give an instance of this variety of day and night within the frigid zones. **73.**

48. What is the length of continuous day and night in the southern part of Nova Zembla? of the periods of alternate day and night? What change goes on in these latter periods with removal towards the poles?

49. What is the greatest length of day within the torrid zone? within the temperate zones? How may the length of the night be obtained from that of the day, and *vice versa?*

50. What is said of the changes of day and night, as to length, at the same place? **74.** Explain why this change proceeds the slowest at the times of the solstices, and the fastest at the times of the equinoxes. Estimate the rate at which the sun's declination increases from the time of the vernal equinox. How does the sun's variable rate of movement between the tropics affect its diurnal course at any given place?

51. Why and when do we have days of the year equalling each other in length? **75.**

52. What is the sum total of daylight at every place upon the earth's surface? **76.** How is this sum made up at the poles? at the equator? between these positions?

53. Were the earth's axis either perpendicular to the plane of its orbit, or coincident with it, what would follow regarding the length of day and night over the earth's surface? Mention a condition which would bring about a constant length of day and night at places in the same latitude, while this length would vary

at places differing in latitude. What condition would bring about a greater variety than we at present have? what a less variety?

THE DIURNAL COURSE OF THE SUN.

54. In what way may we continue a study of the changes which take place in the length of day and night? **77.**

55. At what rate does the sun move above and below the horizon? What kind of a circle does the sun describe upon March 21 and September 21? at other times? Describe its appearance at the north pole upon March 21 and September 21; during the three subsequent months. Is the sun's diurnal course an exact circle?

56. Estimate the sun's advance above a polar horizon, and return to it, during a period of continuous day. With what is the motion of the sun from and to a polar horizon identical?

57. What is said of the points of the compass at the poles?

58. What portion of its diurnal circle does the sun always describe above the horizon at the equator? **78.** Give the reason for the sun's rising in the east and setting in the west at all places upon the earth's surface on March 21 and September 21.

59. Describe the sun's course at the equator during the year.

60. When does the horizon of a place between the equator and the poles have one-half of the sun's diurnal course described above it? **79.** When more than one-half of this course? when less?

61. Why does the sun rise and set at a more rapid advance along the horizon as we remove from the equator?

62. What places have one diurnal circle described above their horizons during the year?

63. Describe the manner in which the rising and the setting sun advances along the horizons of places within the polar circles. **80.** In what direction does the angle between these circles and the horizon diminish?

64. Upon what does the rate at which the sun's diurnal circles ascend above the horizon, or descend towards it, depend?

65. Follow the sun's course at Spitzbergen during a year. **81.**

66. How may the distance at which the sun culminates from

the zenith be known, the sun's declination being given? **82.** Give examples.

67. What is the sun's meridian altitude at Boston, its declination being 10° N.? at New Orleans, its declination being 14° S.?

68. What is said of the sun's culmination within and beyond the torrid zone. **83.**

69. What is said of the sun's culmination at the times of the solstices?

MEASUREMENT OF TIME.

70. Mention different methods employed to measure time. **84.** What is the great standard of time?

71. Define the transit of a heavenly body. **85.**

72. What is a sidereal day? **86.**

73. What is a solar day? **87.** Show, by means of Fig. 13, the reason of the inequality between a sidereal and a solar day.

74. Is this inequality always the same? **88.** What is apparent time? mean time? What constitutes the civil day? How is this day divided? What constitutes the astronomical day?

75. Define the equation of time. **89.** Why is it sometimes added to apparent time, and sometimes subtracted from it, to give the mean time? When is its greatest additive value? its greatest subtractive value? When is the equation of time zero?

76. Explain local time. Give an example illustrating the principle by which the longitudes of places are actually ascertained.

THE SEASONS.

77. What do the changes of the seasons result from? **90.** What two circumstances, already considered, regulate the supply of heat which the earth receives from the sun?

78. Explain the effect which the duration of the day has upon the supply of heat. **91.**

79. What second cause modifies the supply of heat at a given place? Give the quotation. **92.**

80. Give the illustration.

81. Explain why the hottest and coldest periods of the year occur some time after the longest and shortest day. **93.**

82. Does the variation in the distance of the earth from the

sun, as it performs its annual motion, have much influence upon the changes of the seasons ? **94.**

83. What is said of the seasons viewed in connection with the zones ? **95.**

84. What is said of the seasons of the north temperate zone ?

85. Of the seasons of the torrid zone ?

86. Of the seasons of the frigid zones ?

87. Mention local and temporary causes which influence the temperature of a place. **96.**

TWILIGHT.

88. Explain how the atmosphere is conducive to daylight. **97.** How it occasions the season of twilight.

89. Give the illustration.

90. For how long a time, astronomically considered, is twilight generally said to continue ?

91. Upon what does this time depend ? Illustrate the effect of a change of the angle.

92. What is said of twilight at the equator ? at places removed from the equator ?

93. Illustrate upon the globe the varying angle at which the sun proceeds with regard to a given horizon during the year.

94. When do situations north of the equator have their shortest twilight ? when their longest ? When do southern situations have their shortest and their longest twilight ?

95. When does a parallel have morning and evening twilight ? when a twilight lasting from sunset to sunrise ? when a continuous twilight ?

96. Is twilight, ordinarily considered, of the length of astronomical twilight ?

APPENDIX.

It is not known when globes were first constructed; but the first celestial globe is supposed to have been made by Anaximander of Miletus, a pupil of Thales, who flourished in the sixth century before Christ. Ptolemy made use of a terrestrial globe provided with the universal meridian, such as is applied to those now in use. Tycho Brahe had one of copper, nearly five feet in diameter. One eleven feet in diameter, constructed at Limburg, attracted the attention of Peter the Great, who purchased it, and removed it to St. Petersburg. It was large enough to accommodate twelve persons sitting around a table within it. Its inner surface was celestial, the stars being represented by gilded nails; and the outer surface was terrestrial. In 1851 a large globe of novel construction was built in Leicester Square, London, by Mr. Wyld. It was fifty-six feet in diameter, and the delineations were upon the inside only. These were modelled in slabs of plaster of Paris, which were set like a ceiling on the ribs of zinc which formed the framework of the structure. The slabs were cast in clay moulds, which were prepared with care from the most correct maps, on a scale of ten miles to the inch. About six thousand slabs were required to cover the whole surface, their dimensions varying from two feet square as the width diminished towards the poles. The topographical features were represented in relief, and the surface painted in colors. A stairway wound around from the base, by which the circular platforms, one above another, were reached, that brought the spectators near to the inner surface of the great shell.

A globe is made of pasted paper, eight or ten layers of this being applied successively to a mould prepared for the purpose.

As this coating becomes dry, it shrinks, and fits tightly over the mould; from which it is then removed, first being divided into two hemispheres. A turned stick of right length, with a short wire in each end for poles, is now introduced, one end in each hemisphere; and the two shells, being brought together, are secured by gluing their edges. The ball is now hung within a steel semicircle just fitting its exterior, and coated with a composition of glue and whiting. Being made to revolve, the excess of the composition is removed by the circle; and the ball is thus turned smooth and true, after which it is carefully dried. The next process is to lay out the lines of latitude and longitude, which is done by a beam compass. The maps are now to be cut into the segments in which they have been engraved; and these are pasted in succession with white paste upon the foundation, or surface of the ball, the meridian lines drawn upon this surface serving as guides. The fitting requires great care, that the edges may be made to exactly coincide; and some stretching of the equatorial portions is sometimes requisite. When dry, the paper covering is colored, and then sized with gelatine, and immediately varnished. The final process before mounting is to dry again at 200° Fahr. A globe is usually covered with twenty-six pieces of paper; viz., two pole papers or circles including 30° around each pole, and twenty-four gores meeting at the equator. Sometimes the gores extend from the pole to the equator: every gore has then a narrow curved central notch extending 30° from the equator.

INDEX.

Prices Reduced. Boston, December, 1877.

GINN & HEATH,

Publishers,

13 Tremont Place, ... BOSTON.

Terms: Cash in Thirty Days. Trade Price List.

ENGLISH.

A MANUAL OF ENGLISH LITERATURE, Historical and Critical: With an Appendix on English Metres. By THOMAS ARNOLD, M. A., of University College, Oxford. American Edition. Revised. 12mo. Cloth. 549 pages . . . .

CARPENTER'S INTRODUCTION TO ANGLO-SAXON. An Introduction to the study of the Anglo-Saxon Language, Comprising an Elementary Grammar, Selections for Reading with Notes, and a Vocabulary. By STEPHEN H. CARPENTER, Professor of Logic and English Literature in the University of Wisconsin, and Author of "English of the XIV. Century." 12mo. Cloth. 212 pages . . . .

CHAUCER'S PARLAMENT OF FOULES. A revised Text, with Literary and Grammatical Introduction, Notes, and a full Glossary. By J. R. LOUNSBURY, Professor of English in the Sheffield Scientific School of Yale College. 12mo. Cloth. 111 pages . . . .

CRAIK'S ENGLISH OF SHAKESPEARE. Illustrated in a Philological Commentary on his Julius Cæsar, by GEORGE L. CRAIK, Queen's College, Belfast. Edited by W. J. ROLFE, Cambridge. 16mo. Cloth. 402 pages . . . .

ELEMENTS OF GEOMETRY. By GEORGE A. WENTWORTH, Phillips Academy, Exeter.

ENGLISH OF THE XIV. CENTURY. Illustrated by Notes, Grammatical and Etymological, on Chaucer's Prologue and Knight's Tale. Designed to serve as an Introduction to the Critical Study of English. By STEPHEN H. CARPENTER, A. M., Professor of Rhetoric and English Literature in the State University of Wisconsin. 12mo. Cloth. 327 pages . . .

ESSENTIALS OF ENGLISH GRAMMAR, for the Use of Schools. By Prof. W. D. WHITNEY, of Yale College. 12mo. Cloth. 272 pages . . . .

This work is founded on the author's studies of language in general, and on his experience as an examiner in English grammar for one of the departments of Yale College, and as a teacher of French and German in the same institution.

It endeavors to teach the facts of English grammar in such a way as shall lay the best foundation for further and higher study of language in every department.

The work begins with the formation of the simple sentence and the distinction of the parts of speech; it next explains the inflection of English words, and the formation of derivative and compound words: the parts of speech are then taken up in order and treated in detail; and chapters of syntax close the work. The added exercises give due opportunity of practice upon the matters taught.

HUDSON'S CLASSICAL ENGLISH READER. Containing selections from Bryant, Burke, Burns, Byron, Carlyle, Coleridge, Cowley, Cowper, Dana, Froude, Gladstone, Goldsmith, Gray, Helps, Herbert, Hooker, Hume, Irving, Keble, Lamb, Landor, Longfellow, Macaulay, Milton, Peabody, Scott, Shakespeare, Southey, Spenser, Talfourd, Taylor, Webster, Whittier, Wordsworth, and other standard authors. With Explanatory and Critical Footnotes. 12mo. Cloth. 468 pages . . . .

HALSEY'S GENEALOGICAL AND CHRONOLOGICAL CHART of the Rulers of England, Scotland, France, Germany, and Spain. By C. S. HALSEY. Mounted, 33 × 48 inches. Folded and Bound in 4to, 10 × 12 inches . . . .
Unbound . . . .

HALSEY'S BIBLE CHART OF GENEALOGY AND CHRONOLOGY, from the Creation to A. D. 100. Prepared by C. S. HALSEY . . . .
Unbound . . . .

This Chart is designed to illustrate Bible History by showing on a clear and simple plan the genealogy and chronology of the principal persons mentioned in the Scriptures.

HARVARD EXAMINATION PAPERS. Collected and arranged by R. F. LEIGHTON, A. M., Master of Melrose High School. Third Edition, containing papers of June and September, 1875-76. 12mo. Cloth. 348 pages . . . .

These are all the questions (except on the subject of Geometry), in the form of papers, which have been used in the examinations for admission to Harvard College since 1860. They will furnish an excellent series of Questions in Modern, Physical, and Ancient Geography; Grecian and Roman History; Arithmetic and Algebra; Plane and Solid Geometry; Logarithms and Trigonometry; Latin and Greek Grammar and Composition; Physics and Mechanics. They have been published in this form for the convenience of Teachers, classes in High Schools, and especially for pupils preparing for college.

OUR WORLD, No. I.; or, First Lessons in Geography. Revised edition, with new Maps, by MARY L. HALL. Small quarto. 119 pages .

Designed to give children clear and lasting impressions of the different countries and inhabitants of the earth rather than to tax the memory with mere names and details.

OUR WORLD, No. II.; or, Second Series of Lessons in Geography. By MARY L. HALL. With fine illustrations of the various countries, the inhabitants and their occupations, and two distinct series of Maps, 5 pages physical, and 19 pages of finely engraved copperplates political. Quarto. 181 pages . . . .

This book is intended, if used in connection with the First Lessons, to cover the usual course of geographical study. It is based upon the principle that it is more useful to give vivid conceptions of the physical features and political associations of different regions than to make pupils familiar with long lists of places and a great array of statistics.

OUTLINES OF THE ART OF EXPRESSION. By J. H. GILMORE, Professor of Logic, Rhetoric, and English in the University of Rochester. 12mo. Cloth. 117 pages . . . .

This little book was not manufactured to meet a demand, though it is believed that a demand for such a work has long existed. It grew, in the author's class-room, out of an attempt to remedy the defective training in English of students who were, in other respects, qualified to pursue to advantage a college course. With a cursory survey of English Grammar (from the logical and historical point of view) it combines brief practical suggestions with reference to Composition and Rhetoric, together with examples for criticism and topics for practice in the construction of sentences.

PEIRCE'S TABLES OF LOGARITHMIC and TRIGONOMETRIC FUNCTIONS TO THREE AND FOUR PLACES OF DECIMALS. By JAMES MILLS PEIRCE, University Professor of Mathematics at Harvard University. Quarto. Cloth . . . .

PEIRCE'S ELEMENTS OF LOGARITHMS; with an Explanation of the Author's THREE AND FOUR PLACE TABLES. By JAMES MILLS PEIRCE, University Professor of Mathematics at Harvard University. 12mo. Cloth. 92 pages . . . .

This Work is a Companion to THREE AND FOUR PLACE TABLES OF LOGARITHMIC AND TRIGONOMETRIC FUNCTIONS, by the same Authors.

STEWART'S ELEMENTARY PHYSICS. American Edition. With QUESTIONS and EXERCISES. By PROF. G. A. HILL, of Harvard University. 18mo. Cloth. 580 pages . . . .

The Questions will be direct and exhaustive upon the text of Mr. Stewart's work. After the Questions will be given a series of easy Exercises and Problems, designed, in the hands of a good teacher, to arouse and strengthen in the student's mind the power of reasoning in accordance with sound scientific methods.

SEARLE'S OUTLINES OF ASTRONOMY. By ARTHUR SEARLE, of Harvard College Observatory. 16mo. Cloth. 433 pages . .

This work is intended to give such elementary instruction in the principal branches of Astronomy as is required in High Schools or by any students not far advanced in mathematics. It is illustrated by carefully prepared engravings, and contains some information on each of the following subjects: —

1. The chief results of astronomical inquiry up to the present time with regard to the general constitution of the universe, and, in particular, with regard to the stars, planets, nebulæ, comets, and meteors.
2. The methods of astronomical research, and their application to the arts.
3. The general principles of theoretical astronomy.
4. The history of astronomy.
5. Astronomical statistics.

THE ANNALS OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE. Vol. VIII. Results of Observations made or directed by WILLIAM CRANCH BOND, A. M., GEORGE PHILLIPS BOND, A. M., and JOSEPH WINLOCK, A. M. Quarto. Cloth . . . . .

PART I. — Historical Account of the Observatory from October, 1855, to October, 1876.

PART II. — I. Astronomical Engravings of the Moon, Planets, etc.
II. Astronomical Engravings illustrating Solar Phenomena.

THE ATLANTIC PRIMARY ARITHMETIC. Simple Numbers. By G. L. DEMAREST. 16mo. 256 pages . . . .

THE ELEMENTS OF PLANE TRIGONOMETRY. By H. N. WHEELER, A. M., of Cambridge. 12mo. Cloth. 120 pages . .

THE LIVING WORD; or, Bible Truths and Lessons. 12mo. Cloth. 158 pages . . . .

THE ODES OF HORACE, IN ENGLISH VERSE. By CASKIE HARRISON, Professor of Ancient Languages in the University of the South. Part I., containing the First Book. 12mo. Paper Cover . . .

THE TEACHER'S IMPROVED CLASS-BOOK.

18mo. 42 pages. Stiff paper cover . . . .
" 92 " Cloth . . . .

Two advantages result from the arrangement of pages adopted in the IMPROVED CLASS BOOK: 1. The names of pupils in any class need to be entered *but once for an entire term*. 2 The standing for the three months, instead of needing to be compiled from different parts of the book, is present to the eye at one view.

MUSIC.

THE NATIONAL MUSIC COURSE. In Four Books. For Public Schools. By JULIUS EICHBERG, J. B. SHARLAND, L. W. MASON, H. E. HOLT, Supervisors of Music in Public Schools of Boston, Mass.

PRIMARY OR FIRST MUSIC READER. 16mo. 96 pages . . . .

A course of exercises in the elements of VOCAL MUSIC AND SIGHT-SINGING, with choice rote songs for the use of youngest pupils.

INTERMEDIATE MUSIC READER. 16mo. 192 pages

Including the Second and Third Music Readers. A course of instruction in the elements of Vocal Music and Sight-Singing, with choice rote songs, in two and three parts, based on the elements of harmony.

THE FOURTH MUSIC READER. 8vo. 336 pages . . .

This work, prepared to follow the Third Music Reader, is also adapted, under a competent instructor, to be used in High Schools where no previous systematic instruction has been given. To this end a brief but thorough elementary course is given, with musical theory, original solfeggios, a complete system of triad practice, and sacred music and song, with accompaniment for the piano. The music introduced is of a high order, and by the best masters, and is calculated to cultivate the taste, as well as to extend the knowledge and skill of the pupils.

THE FIFTH, or HIGH SCHOOL MUSIC READER FOR MIXED VOICES. Containing a full Course of Advanced Solfeggios for One and Two Voices, and a carefully selected number of easy *Four*-Part Songs, taken from the works of the best composers. This work has been especially compiled to meet the growing wants of our High Schools for a higher grade of music than is contained in works now used in such schools. 8vo. 299 pages .

N. B. — The Tenor Part in many of the songs may be either omitted or sung by the altos (boys)

THE ABRIDGED FOURTH MUSIC READER. 8vo. 288 pages . .

THE SECOND MUSIC READER. 16mo. 96 pages . . . . . .

THE THIRD MUSIC READER. 16mo. 96 pages . . . .

THE NATIONAL MUSIC CHARTS. By LUTHER WHITING MASON. An invaluable aid to Teachers of Common Schools in imparting a practical knowledge of Music, and teaching Children to sing at sight. In Four Series. Forty Charts each, size 25 × 36 inches.

FIRST SERIES . . . .
SECOND SERIES . . . .
THIRD SERIES . . . .
FOURTH SERIES by L. W. MASON and J. B SHARLAND . . . . . .
EASEL . . . .

THE NATIONAL MUSIC TEACHER. A Practical Guide for Teaching Vocal Music to Young Children. By L. W. MASON. 8vo. 72 pages . . . .

GERMAN.

A COURSE IN SCIENTIFIC GERMAN. Prepared by H. B. HODGES, Instructor in Chemistry and German in Harvard University. With Vocabulary. 12mo. Cloth. 182 pages . . . .

This book has been prepared to supply a want long felt by English and American students of science, of some aid in the acquirement of a knowledge of the German language of a sufficiently practical nature to enable them to read with ease the scientific literature of Germany.

GREEK.

GOODWIN'S GREEK GRAMMAR. By William W. Goodwin, Ph. D., Eliot Professor of Greek Literature in Harvard University. 12mo. Half morocco. 262 pages . . . .

The object of this Grammar is to state *general principles* clearly and distinctly, with special regard to those who are preparing for college. In the sections on the Moods are stated, for the first time in an elementary form, the principles which are elaborated in detail in the author's "Syntax of the Greek Moods and Tenses."

GREEK MOODS AND TENSES. The Sixth Edition. By William W. Goodwin, Eliot Professor of Greek Literature in Harvard University. 1 vol. 12mo. Cloth. 264 pages . . . .

This work was first published in 1860, and it appeared in a new form — much enlarged and in great part rewritten — in 1865. In the present edition the whole has been again revised; some sections and notes have been rewritten, and a few notes have been added. The object of the work is to give a plain statement of the principles which govern the construction of the Greek Moods and Tenses, — the most important and the most difficult part of Greek Syntax.

GOODWIN'S GREEK READER. Consisting of Extracts from Xenophon, Plato, Herodotus, and Thucydides; being the full amount of Greek Prose required for admission at Harvard. With Maps, Notes, References to GOODWIN'S GREEK GRAMMAR, and parallel References to CROSBY'S and HADLEY'S GRAMMARS. Second edition, edited by Professor W. W. Goodwin, of Harvard College. 12mo. Half morocco. 384 pages . . . . .

The revised edition contains the first and second books of the Anabasis (in place of the third and fourth books of the former editions) with copious notes, the greater part of the second book and an extract from the seventh of the Hellenica, with the first chapter of the Memorabilia, of Xenophon; the last part of the Apology, and the beginning and end of the Phaedo, of Plato; selections from the sixth, seventh, and eighth books of Herodotus, and from the fourth book of Thucydides.

GOODWIN'S SELECTIONS FROM XENOPHON AND HERODOTUS. With Notes adapted to Goodwin's Greek Grammar, Parallel References to Crosby's and Hadley's Grammars, and copper-plate Maps. Edited by Professor W. W. Goodwin and John Williams White, of Harvard College. 12mo. Half morocco 408 pages . . . .

This book contains the first four books of the Anabasis, and the greater part of the second book of the Hellenica, of Xenophon; and extracts from the sixth, seventh, and eighth books of Herodotus. It has been prepared for the use of those who from want of time or for other reasons are unable to read the greater variety of selections in Greek Prose which are contained in Goodwin's Greek Reader.

THE FIRST FOUR BOOKS OF THE ANABASIS OF XENOPHON. Edited, with copious Notes and References to Goodwin's Greek Grammar, Parallel References to Crosby's and Hadley's Grammars, and a copper-plate Map, by Professor W. W. Goodwin and John Williams White, of Harvard College. 12mo. Half morocco. 240 pages . . . . . .

LEIGHTON'S GREEK LESSONS. Prepared to accompany Goodwin's Greek Grammar. By R. F. Leighton, Master of Melrose High School. 12mo. Half morocco. 264 pages . . . .

This work contains about one hundred lessons, with a progressive series of exercises (both Greek and English), mainly selected from the first book of Xenophon's Anabasis. The exercises on the Moods are sufficient, it is believed, to develop the general principles as stated in the Grammar. The text of four chapters of the Anabasis is given entire, with notes and references. Full vocabularies accompany the book.

LIDDELL & SCOTT'S GREEK-ENGLISH LEXICON. Abridged from the new Oxford Edition. New Edition. With Appendix of Proper and Geographical Names, by J. M. WHITON. Square 12mo. 835 pages.

Morocco back . . . .
Sheep binding . . . .

LIDDELL & SCOTT'S GREEK-ENGLISH LEXICON. The sixth Oxford Edition unabridged. 4to. 1,881 pages.

Morocco back . . . .
Sheep binding . . . .

The English editions of Liddell & Scott are *not stereotyped*; but each has been thoroughly revised, enlarged, and printed anew. The sixth edition, published in 1869, is larger by one eighth than the fifth, and contains 1,865 pages. It is an *entirely different work* from the first edition, the whole department of etymology having been rewritten in the light of modern investigations, and the forms of the irregular verbs being given in greater detail by the aid of Veitch's Catalogue. No student of Greek can afford to dispense with this invaluable Lexicon, the price of which is now for the first time brought within the means of the great body of American scholars.

PLATO'S APOLOGY OF SOCRATES AND CRITO. Edited by JOHN WILLIAMS WHITE, Ph. D., Assistant Professor of Greek in Harvard University.

The basis of this work will be the German edition of Dr. Christian Cron. (Platons Vertheidigungsrede des Sokrates und Kriton. Sechste Auflage. Leipzig, Teubner, 1875.) To the matter contained in Dr. Cron's edition there will be added notes by the Editor and from other sources, analyses, and extended references to Goodwin and Hadley. The book will be for the class-room, and all matter not of direct value to the student will be rigidly excluded.

THE ŒDIPUS TYRANNUS OF SOPHOCLES. Edited, with an Introduction, Notes, and full explanation of the metres, by JOHN WILLIAMS WHITE, Ph. D., Assistant Professor of Greek in Harvard University. 12mo. Cloth. 219 pages . . . .

THE MEDEA OF EURIPIDES. Edited, with Notes and an Introduction, by FREDERIC D. ALLEN, Ph. D., Professor in the University of Cincinnati. 12mo. Cloth. 141 pages . . . .

SIDGWICK'S INTRODUCTION TO GREEK PROSE COMPOSITION. 12mo. Cloth. 280 pages . . . . . .

WHITE'S FIRST LESSONS IN GREEK. Prepared to accompany Goodwin's Greek Grammar, and designed as an Introduction to his Greek Reader. By JOHN WILLIAMS WHITE, Ph D., Assistant Professor of Greek in Harvard University. 12mo. Half morocco. 305 pages . . . .

A series of seventy-five lessons with progressive Greek-English and English-Greek exercises. Followed by a series of additional exercises on Forms, and complete vocabularies.

WHITON'S SELECT ORATIONS OF LYSIAS. Comprising the Defence of Mantitheus, the Oration against Eratosthenes, the Reply to "The Overthrow of the Democracy," and the Areopagitic Oration concerning the Sacred Olive-Trunk. Edited by JAMES MORRIS WHITON, Ph. D. 12mo. 151 pages . . . .

The grammatical notes deal almost wholly with the syntax,—as befits a work of this grade,—and have been prepared with a special aim to elucidate the usage of the verb. References are made, for the most part, to Goodwin's Greek Moods and Tenses, and Goodwin's and Hadley's Grammars.

YONGE'S ENGLISH-GREEK LEXICON. Square 12mo. Cloth. 483 pages . . . .

LATIN.

ALLEN & GREENOUGH'S LATIN GRAMMAR: a Latin Grammar for schools and colleges, founded on Comparative Grammar. 12mo. Half morocco. 290 pages (including supplementary Outlines of Syntax, with new and greatly enlarged Index) . . . .

The features of this grammar to which we invite attention, are: 1. The scientific form of statement in the Etymology, corresponding to the most advanced views of comparative philologists; 2. The comparison with kindred languages suggested throughout, especially in numerous brief philological notes, and in references to the syntax of Goodwin's Greek Grammar; the grouping and subordination of topics in the Syntax,— which contains nearly 200 cross-references, with upwards of 1,000 citations from classic authors,— so that unusual brevity is attained without sacrifice of completeness.

ALLEN & GREENOUGH'S LATIN METHOD: a Method of Instruction in Latin; being a companion and guide in the study of Latin Grammar. With elementary instruction in Reading at Sight, Exercises in Translation and Writing, Notes, and Vocabularies; also "Outlines of Syntax," taken from the Latin Grammar. 12mo. Cloth. 134 pages . . .

ALLEN & GREENOUGH'S LATIN COMPOSITION: an Elementary Guide to Writing in Latin. Part I. Constructions of Syntax; Part II. Exercises in Translation. 12mo. Cloth. 198 pages . . . .

Part First (which is published separately) consists of thirty progressive Lessons, with full instructions, exercises, and vocabulary; and is designed "to furnish a sufficient amount of study and practice in Latin composition during the last year of preparation for college, or the first of a college course." Part Second consists of about forty exercises in translation, chiefly narrative, adapted to the use of advanced or college classes; with annotated references to the Lessons of Part I., and to the sections of a special Introduction on the Choice of Words, the Form of the Sentence, and Idiomatic Usages.

ALLEN & GREENOUGH'S CÆSAR: Cæsar's Gallic War: Four Books. With Historical Introduction, Notes, and a Copperplate Map of Gaul. [With a full Vocabulary by R. F. PENNELL, of Phillips Exeter Academy.] 12mo. Half morocco. 282 pages . . . .
Without Vocabulary . . . .

The text of this edition is that of Nipperdey, important variations being noticed. The notes are unusually full in historical illustration, derived largely from Mommsen, Long, Merivale, the "History of Julius Cæsar" by Napoleon III., and the excellent school edition of Moberly. In the earlier portions they are especially designed to guide in a systematic and careful study of Latin syntax.

ALLEN & GREENOUGH'S SALLUST: The Conspiracy of Catiline as related by Sallust. With Introduction and Notes explanatory and historical. 12mo. Cloth. 84 pages . . . .

ALLEN & GREENOUGH'S CICERO: Select Orations of Cicero, chronologically arranged, covering the entire period of his public life. From the text of Baiter and Kayser. With Life, general and special Introductions, and Index of topics discussed. 12mo. Half morocco. 394 pages . .
The text without notes . . . .

It is the design of this edition to give a full view of Cicero's public career, as orator and statesman, extending through about forty of the most eventful years of the later Republic. With this view, the selection includes the earliest and the latest of his public orations, while the special Introductions cover very fully the intervening political history. Besides the orations more commonly read in schools, are given the Roscius and Sestius (abridged), with the first against Verres and the last Philippic,— thirteen in all,— with one or two short passages of special celebrity, for practice in reading at sight. Especial care has been taken in the department of Antiquities, which has been treated in numerous notes (in smaller type), some of them — as that on the Roman Aristocracy — being brief essays on the several topics.

The Introduction contains a classified list of all the works of Cicero, with the occasions and topics of all of his orations.

ALLEN & GREENOUGH'S CATO MAJOR: Cicero *De Senectute*, a Dialogue on Old Age. With Introduction (on the adoption in Rome of the Greek philosophy) and Notes. 12mo. Cloth. 57 pages . .

ALLEN & GREENOUGH'S OVID: Selections from the Poems of Ovid, chiefly the *Metamorphoses*. With special Introductions, Notes, and Index of Proper Names. 12mo. Half morocco. 283 pages . . .

The introductions to the passages from the *Metamorphoses* (28 in number) give the entire argument of the poem, that of omitted portions bracketed. The other selections include those of special interest as illustrating the poet's life; and a list is given of all his writings, with their topics and occasions. The Notes contain brief instructions on scanning at sight.

ALLEN & GREENOUGH'S VIRGIL: The Poems of Virgil; Vol. I. containing the Pastoral Poems (*Bucolics*) and Six Books of the Æneid. Chiefly from the text of Ribbeck, with select various Readings, Introductions, Notes, and Index of Plants (compiled chiefly from Fée's *Flore de Virgile*, contained in Lemaire's "Bibliotheca Classica Latina"). 12mo Half morocco. 372 pages . . . .
The text without notes . . . .

The Notes of this edition (which are brief and very numerous) are particularly indebted to Conington, and are designed "to give not only what may serve the learner in the bare understanding of the text; but, along with it, some hint of that wealth of traditional interpretation which is more important, perhaps, in the study of Virgil than in that of any other ancient poet."

ALLEN & GREENOUGH'S VIRGIL. With Vocabulary. 12mo. Half morocco. 588 pages . . . .

ALLEN & GREENOUGH'S Course No. I. A Full Preparatory Course of Latin Prose; consisting of Four Books of Cæsar's Gallic War, Sallust's Conspiracy of Catiline, Eight Orations of Cicero, and DE SENECTUTE (*Cato Major*). 12mo. Half morocco. 582 pages . . . . . .

ALLEN & GREENOUGH'S Course No. II. Second Preparatory Course of Latin Prose; containing Four Books of Cæsar's Gallic War, and Eight Orations of Cicero. With Vocabulary by R. F. PENNELL. 12mo. Half morocco. 518 pages . . . .

N. B. *Course No. I. is identical with the First Course prescribed for admission to Harvard College. Course No. II. includes the usual amount required at other colleges.*

ALLEN & GREENOUGH'S CICERO. Eight Orations of Cicero. With Vocabulary by R. F. PENNELL. 12mo. Half morocco. 358 pages . . . .

ALLEN'S LATIN GRAMMAR. 12mo. Cloth. 182 pages

ALLEN'S LATIN LESSONS. 12mo. Cloth. 146 pages .

ALLEN'S LATIN READER: Consisting of Selections from Cæsar (the invasion of Britain and account of the Gallic and German populations), Curtius (Anecdotes of Alexander), Nepos (Life of Hannibal), Sallust (Jugurtha, abridged), Ovid, Virgil, Plautus, and Terence (single scenes), Cicero and Pliny (Letters), and Tacitus (the Conflagration of Rome). With Notes and a General Vocabulary. The Notes have been adapted to Allen & Greenough's Grammar. 12mo. Half morocco. 582 pages . . . .

ALLEN'S LATIN SELECTIONS. Containing the first 134 pages of Allen's Latin Reader. With Notes adapted to A. & G.'s Latin Grammar. 12mo. Half morocco. 190 pages . . . .